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DEMONSTRATION OF A LOGISTICS SUPPORT COST MODEL FOR STAGE III OF THE DIGITAL EUROPEAN BACKBONE PROGRAM

THESIS

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Galen J. Rose
Major USAF

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THESIS

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(10) Galen J. Rose, B.S.
Major USAF

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Preface

This thesis is the result of my efforts of developing a cost model for comparing alternative digital radio equipment for Stage III of the Digital European Backbone Upgrade Project. The study develops and demonstrates a life cycle logistics support cost model representing relevant initial investment costs and recurring maintenance and supply support costs. This cost-based methodology provides a systematic approach to estimating relative cost magnitudes and relative cost differentials as figures of merit between equipment alternatives.

I want to express my gratitude to my advisor, Lt. Col. Adrian Harrell, and my reader, Dr. Keith Womer for sticking with me to the bitter end and providing the much needed direction, guidance and impetus toward the accomplishment of this project. Also, to my typist, Mrs. Charlette Kjesbo, I express my thanks for a fine job.

I especially wish to express sincere appreciation to my family for their patience, understanding, and encouragement through the many frustrations and essentially doing without me during the past fifteen months. My wife, Sharon, deserves a special vote of thanks for the many hours spent at an 18 year old typewriter. I promise them all better times in the future.

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Abstract

This study provides a cost-based methodology for comparing alternative fixed ground communications radios. The study develops and demonstrates a life cycle logistics support cost model representing relevant initial investment costs and recurring maintenance and supply support costs. The scope of the study addresses only Stage III of the Digital European Backbone Upgrade Project. The cost model developed is an accounting model that aggregates the cost of thirteen separate cost element equations and requires 54 input data values. This methodology provides a systematic approach to estimating the relevant costs of proposed equipment options over their expected usage period. The model yields estimated cost results that indicate relative cost magnitudes and relative cost differential comparisons as figures of merit between equipment alternatives.

I. Introduction

Program Overview

The Defense Communications Agency (DCA), in conjunction with the military departments, is embarking on the initial phase of improving worldwide military communications. The objective is to upgrade the various Defense Communications Systems (DCS) incrementally, as plans and requirements evolve from system improvement plans (Hq. USAF, Program Management Directive, 1975:18). The Digital European Backbone (DEB) Upgrade Project is the first in this expected series of efforts for an overall Defense Communications System wideband transmission improvement program.

The present European wideband communications system is a mix of several types of older communication subsystems. This non-standard assemblage of equipment is considered technically obsolete and presents maintenance, logistics and operational problems. The Digital European Backbone Program is to improve the terrestrial European wideband communications subsystem that extends from Italy through the Federal Republic of Germany and Belgium into England (Defense Communications Agency, 1975:1-1).

The European backbone project is a joint service operation with the United States Air Force designated as the military department of primary responsibility for implementation. Program management for implementation of the upgrade project is the Electronic Systems Division (ESD/DCF) Digital

European Backbone System Program Office. The Army is responsible for development and acquisition of various radio equipment required for the Digital European Backbone upgrade project (Defense Communications Agency, 1975:3-1). Specifically, the project is to upgrade most of the existing equipment with modern, reliable, digital transmission subsystems. The European Defense Communications System will be transitioned from a nonsecure analog system to a predominately digital bulk encrypted system.

The Digital European Backbone Program is scheduled to be implemented in four stages. Figure 1 depicts the first three stages which constitute the main backbone of the European communications system.

Stage I. The upgrade for Stage I involves thirteen sites. Four are operated and maintained by the Army and the remainder are Air Force controlled. Stage I extends from Coltano, Italy north to Vaihingen, Germany, with a desired operational date of November 1977. Equipment for all thirteen sites is being acquired by the Army. New radio equipment needs for Stage I will be a Defense Communications System microwave radio modified to satisfy the transmission requirements for that increment of the upgrade program.

Stage II. Seven Army sites and six Air Force sites make up Stage II of the project. Stage II, which will extend from Vaihingen to Schoenfeld in Central Germany, is to be operational in June 1978. These communication sites have older, obsolete radio equipment that is projected to be replaced

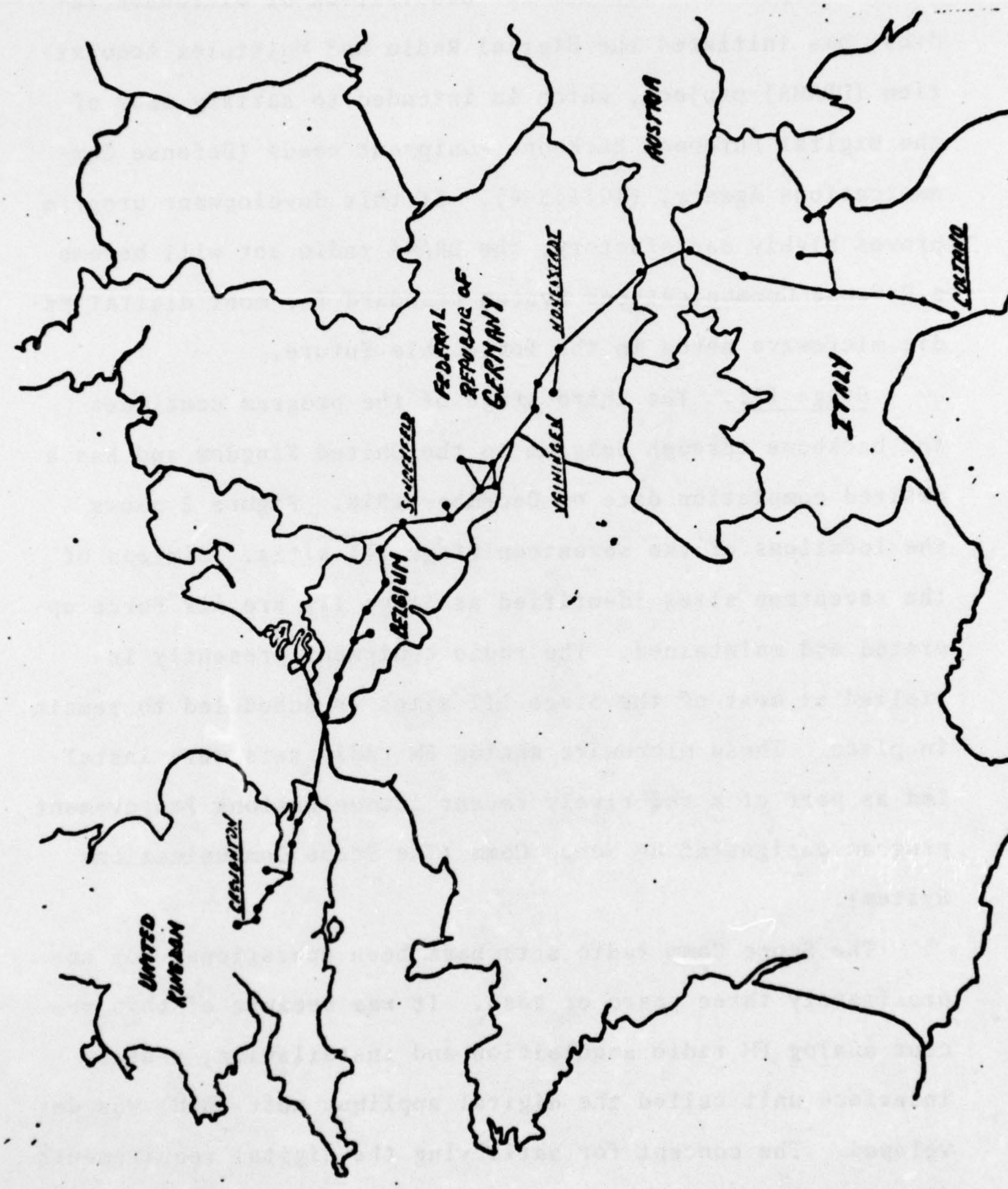

Fig. 1. Digital European Backbone Program

with a new digital radio developed by the Army. The Army, as the responsible service for acquisition of microwave radios, has initiated the Digital Radio and Multiplex Acquisition (DRAMA) project, which is intended to satisfy many of the Digital European Backbone equipment needs (Defense Communications Agency, (1975:5-4). If this development program proves highly satisfactory, the DRAMA radio set will become a Defense Communications System standard for most digital radio microwave needs in the forseeable future.

Stage III. The third stage of the program continues the backbone through Belgium to the United Kingdom and has a desired completion date of December 1978. Figure 2 shows the locations of the seventeen Stage III sites. Sixteen of the seventeen sites identified as Stage III are Air Force operated and maintained. The radio equipment presently installed at most of the Stage III sites is scheduled to remain in place. These microwave analog FM radio sets were installed as part of a relatively recent communications improvement program designated as Scope Comm (The Scope Communications System).

The Scope Comm radio sets have been operational for approximately three years or less. It was because of this recent analog FM radio acquisition and installation, that an interface unit called the digital applique unit (DAU) was developed. The concept for satisfying the digital requirements for Stage III using the existing Scope Comm radios was developed through the Rome Air Development Center (RADC), Griffiss

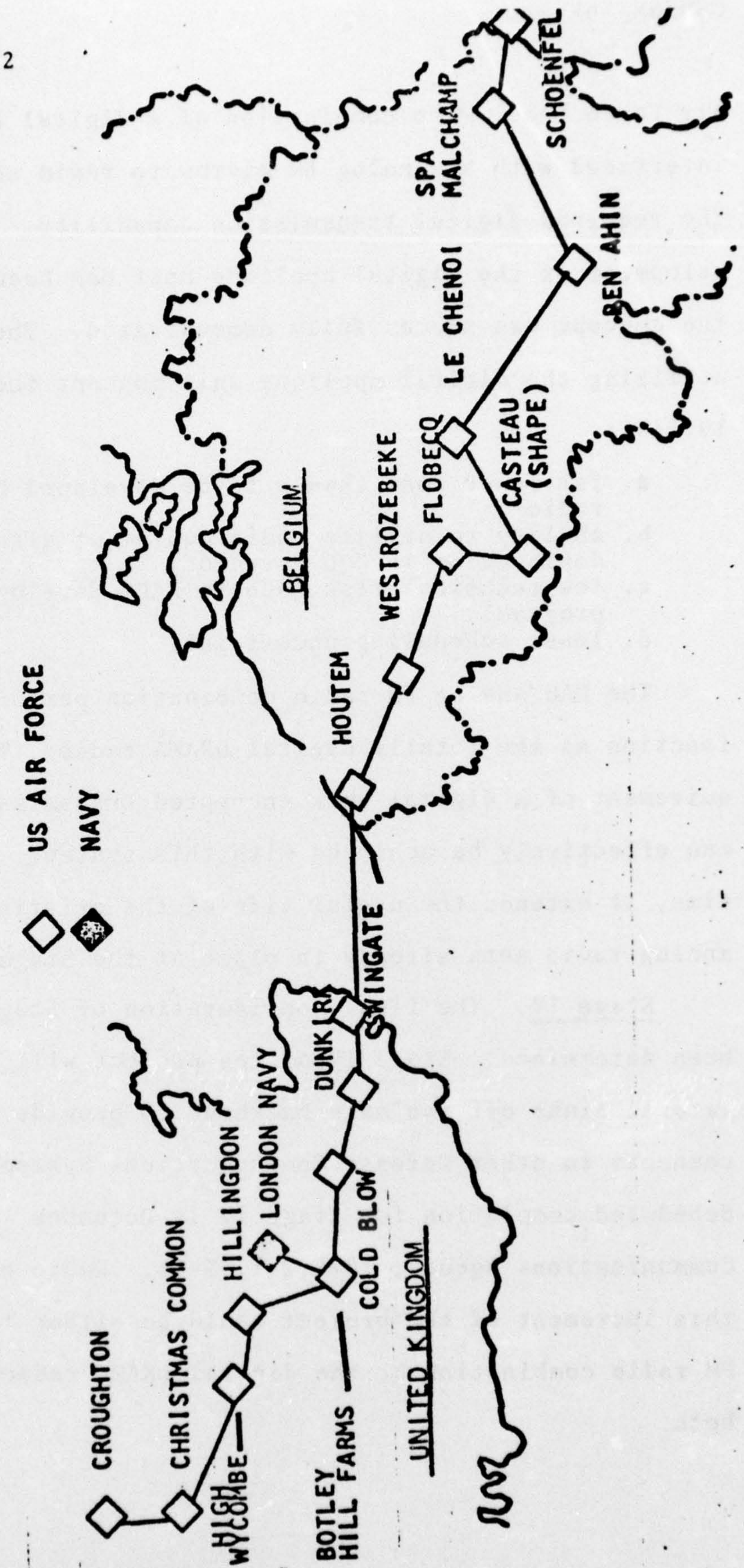

Fig. 2. Stage III Digital European Backbone

Air Force Base. The combination of a digital applique unit, interfaced with an analog FM microwave radio set, provides the required digital transmission capability. Prototype development of the digital applique unit has been completed and the concept was successfully demonstrated. The advantages of utilizing the digital applique unit concept include (Post, 1975:5):

a. far lower cost than a to-be-developed DRAMA radio
b. ability to utilize radio equipment already deployed or in DOD inventory
c. low technical risk (due to RADC development program)
d. lower scheduling uncertainty

The DAU/Analog FM radio combination performs the same function as the totally digital DRAMA radio. The basic requirement of a digital bulk encrypted transmission capability can effectively be achieved with this system. At the same time, it extends the useful life of the existing Scope Comm analog radio sets already in place at the Stage III sites.

Stage IV. The final configuration of Stage IV has not been determined. Stage IV of the project will consist of lateral links off the main backbone to provide digital interconnects to other Defense Communications System users. Scheduled completion for Stage IV is December 1979 (Defense Communications Agency, 1975:2-1, 5-1). Radio equipment for this increment of the project could be either the DAU/Analog FM radio combination or the digital DRAMA radio or a mix of both.

Statement of the Problem

The selection of the digital equipment configurations for Stages II and III of the Digital European Backbone Program are preliminary decisions based on estimated technical and cost considerations. Because the DAU/FM analog radio combination and the digital radio (Army DRAMA project) can perform the same function, they both remain viable alternatives to fulfill the digital requirements for Stages II, III and IV. Final decisions for the digital equipment to be utilized in these stages will be made as soon as sufficient technical and cost data is available to conduct a tradeoff analysis between equipment alternatives.

Throughout the department of defense, continued emphasis is being placed on those costs incurred beyond acquisition of new or modified hardware costs. It is important in most tradeoff studies to determine the expected long term operating and support costs for potential systems. It is not uncommon for the maintenance and support costs to exceed the original cost of acquisition by several times. Escalating operating and support costs and reduced defense budgets make it essential that managers and planners are not only aware of what it costs to buy new equipment, but also how much it costs to operate and support that equipment for its programed life span.

At the present time, initial cost estimates for the digital applique unit and the digital radio have been concentrated on production costs and those initial costs required

to bring the system into the operational inventory. It is extremely difficult to make adequate tradeoff analyses in the early conceptual planning and design phases of a system. Equipment characteristics such as reliability and maintainability are not available in sufficient detail to obtain maintenance and support cost estimates. Prototype development results will normally yield equipment reliability and maintainability characteristics that are needed in computing equipment maintenance and support costs.

Data is currently available from the digital applique development to support a life cycle support cost analysis. The request for proposal of the digital radio prototype development should be released by the end of the fiscal year and the required data from that development is not expected until sometime in the calendar year 1977.

This thesis addresses the problem of estimating the long term maintenance and support costs of the Digital European Backbone Stage III radio equipment alternatives. The study focuses on providing the methodology for computing and comparing the life cycle support cost estimates of the Digital equipment alternatives. The scope of the cost estimates are limited to the relevant costs associated with the Stage III sites and the DAU/FM analog radios or the digital radio.

Thesis Objective

The objective of this thesis is to develop and demonstrate the utility of a life cycle logistics support cost

model as a decision aid when discriminating between equipment alternatives. The model developed, could provide the methodology for cost comparisons to be used in future tradeoff studies following the completion of the digital radio prototype development. The model developed in Chapter III represents the maintenance and supply support concepts presently in effect at the Stage III communication sites. It computes the initial nonrecurring acquisition costs and the recurring costs expected over a span of ten years. The model will provide a systematic approach to estimating the relevant costs of the Stage III digital equipment alternatives.

Methodology

The methodology used in this study was to estimate the cost of operating and supporting the Stage III radio equipment using a cost model developed for that specific situation. The approach used to develop the model and compute the desired cost estimate included the following steps:

1. The initial emphasis was a literature review of system life cycle estimating techniques. The literature search and review served as the educational process to relate cost analysis to the specific area of life cycle costing methodologies. Personal interviews were conducted with Air Force cost estimating personnel from the Aeronautical Systems Division, Electronics Systems Division and Air Force Logistics Command.

2. A basic understanding of the Digital European Back-

bone Program and the operational environment of the communications equipment was required. This was accomplished by a review of program related literature, system technical reports, technical orders and discussions with a great many personnel involved in the project.

3. Cost elements had to be identified. Working from a framework of major cost categories normally associated with military systems, relevant subcategories and specific cost elements determined applicable to this study were broken out and defined.

4. Next, a cost model was formulated to represent the cost elements. Mathematical equations were created to express the cost function of each cost element. The cost element equations were then combined into a computerized version of the basic cost model.

5. The cost estimate results were obtained by exercising the computer model. Data obtained from a variety of program related sources was input into the computer for the final cost model results.

Life cycle cost is the total cost of a system or given piece of equipment over its useful life. It includes all the costs of research and development, acquisition and ownership (operations, maintenance and support). According to Menker, life cycle costing is the consideration of life cycle costs or segments thereof and one of the principal activities is the preparation of cost estimates for the area of concern (Menker, 1975:1-4). This study effort focused its attention

on the cost categories of acquisition, maintenance and supply support. Only those costs which were determined to be the most relevant within these three cost categories were considered.

Gibson states that the effective application of life cycle costing generally requires the use of a cost model (Gibson, October 1975:1). A cost model consists of mathematical relationships arranged in a systematic sequence designed to obtain the resultant cost estimate. There are many types of cost models in existence. Some attempts have been made to develop generalized models that can be adapted for particular situations, while others were developed for a specific system. One of the more widely used models is the Air Force Logistics Command's Logistics Support Cost (LSC) Model.

The Logistics Support Cost Model in its general form was not appropriate for the fixed ground communications environment addressed in the study. However, the model adapted for this study was developed using the general Air Force Logistics Support Cost Model as a pattern.

Assumptions

The following basic assumptions were necessary to this study's life cycle support cost estimating process:

1. The data obtained from the Maintenance Data Collection System (Air Force Manual 66-1, Maintenance Management) resulted in a valid representation of the maintenance effort.

2. Data obtained from the digital applique unit's prototype development technical report is a reasonable representation of its equipment characteristics.

3. The existing maintenance and supply support concepts described and modeled in Chapter III are expected to be the same for the new equipment alternatives.

Limitations

The scope of the research study was limited in the following ways:

1. The cost model designed for this study was adapted to represent the fixed ground radio subsystem operation presently in use at the Scope Comm sites in Europe. If basic maintenance concepts change or differ, cost parameters change, or any other cost elements change, this would require another iteration of the model. The results expressed in this study reflect conditions and costs at the time of data collection.

2. The model is limited to those cost elements determined essential by the researcher. It is extremely difficult to determine all operating and support costs that may be attributed to individual equipment. Various indirect support costs such as electrical power consumption, facility maintenance, administrative and support personnel costs were not included.

3. The scope of this study is limited to the development of a life cycle support cost model useful for making cost

comparisons between digital equipment alternatives for Stage III only.

Nature and Sources of Data Requirements

Data requirements to support the cost model came from a variety of sources. The nature and sources of most data were:

1. The Electronic System Division program office (DCF) and cost analysis branch (ACF) furnished estimated production costs of the digital applique unit. They were supplied information from Rome Air Development Center engineers on the prototype development of the DAU. Using this information, estimates of system acquisition costs were obtained from the PRICE model. The PRICE (Programmed Review of Information for Costing and Evaluation) model is a large-scale, computerized model, that estimates "probable costs" in the early development of a system.

2. The Sacramento Air Logistics Center furnished price data on the analog FM radio equipment parts and modules.

3. Headquarters European Communications Area furnished maintenance system data, cost data and other system related information.

4. The digital applique unit prototype was developed under the project management of Rome Air Development

Center microwave system engineers. They supplied a copy of the contractors technical report which included maintenance and reliability information. They also obtained initial cost estimates for digital applique modules.

5. Several official publications were also useful for obtaining standard cost factors. They included:

   a. DCA Circular 600-60-1; Defense Communications Agency Cost and Planning Factors Manual

   b. AFR 173-10 Vol. I (C2), USAF: Cost and Planning Factors

   c. AFLCP 173-10, Air Force Logistics Command: Cost and Planning Factors

<u>Overview of Remaining Chapters</u>

Chapter II - <u>Background</u> discusses life cycle cost, cost models in general terms, supportive cost model concepts, system cost categories and related factors associated with cost model development.

Chapter III - <u>Model Formulation</u> includes definitions of important concepts and factors that are fundamental parameters to consider in developing a support cost model. It also includes a description of the maintenance and supply support policies anticipated for Stage III equipment operation. Finally, it defines the major cost elements of the model and describes, in detail, the individual cost element equations, parameters and variable names used in the model.

Chapter IV - <u>Model Results</u> provides a demonstration of

the model based on the data collected for the DAU/Analog FM radio equipment, specific parameters will be changed to analyze the effect on the resultant cost. This chapter will conclude with a demonstration of the cost model in comparing equipment alternatives.

Chapter V - Summary will present a concise summary of the study, state conclusions and recommendations.

II. Background

The purpose of this chapter is to present a background of cost analysis concepts and considerations involved in the development of a support cost estimating model. Initial discussion points out the need for life cycle cost estimates of defense systems. This is followed by a general cost analysis description of military system cost categories. The categories of development, investment and operations are further separated into subcategories of a systems total life cost. As mentioned in the preceding chapter, this study is to estimate the relevant support costs of the microwave radio equipment using a modified version of an existing model. A brief review of existing model types is presented and the chapter concludes with a discussion of the Air Force Logistics Support Cost Model.

Total Cost Visibility

In the past several years, such factors as declining defense budgets, inflation, rapidly increasing costs of new systems and higher operating and support costs, has produced renewed Department of Defense management emphasis to reduce costs in all areas. With the trend toward reduced defense spending, the Department of Defense is faced with the problem of doing more with less resources. Therefore, the military departments are confronted with the challenge to reduce acquisition, operating and support costs of our defense systems (Gansler, 1975:3).

Historically, visibility has not been concentrated on the cost or expected cost to operate and support weapon systems. Operation and support of a weapon system was viewed as a given fixed cost that must be accepted when introducing a new system into the inventory. In the majority of cases, most of the effort to estimate costs has been directed toward the production and acquisition of a system, with little attention to the cost of a system once it becomes operational. Dr. John J. Bennet, Acting Assistant Secretary of Defense for Installations and Logistics, states the following reasons why the area of acquisition receives more attention than follow on operating costs (Bennet, 1976:2).

1. The Department of Defense has more experience in controlling production costs than operating and support costs.

2. Operating and support costs are more complex and insufficiently understood.

3. The operating and support cost data base is incomplete and is just now being developed.

The need to estimate all costs related to weapon or support systems not only pertains to new systems, but also includes analysis of existing operational systems. Studies of current operational field experience data indicate that high ownership costs are not limited to new or complex subsystems (Gibson, 1976:1). Defense system Managers require cost visibility into existing operational systems to identify high operating cost items and determine the need for modification or replacement.

One aspect of the recent emphasis on the total cost prob-

lem, deals with the concept of system life cycle cost (LCC). Life cycle costing is an analysis process to provide total cost visibility of development, acquisition and operation of a system over its full life. Using the concept of life cycle cost, this study estimates the acquisition and support costs associated with two types of microwave radio equipment. The digital applique unit is a new development that will interface with existing operational microwave radio sets. The cost estimate obtained from this study, will provide visibility of life cycle support costs associated with the combined operaton of new and existing equipment.

Cost Analysis and Related Life Cycle Categories

To facilitate the understanding of life cycle cost concepts, it was necessary to review the nature and role of the process of cost analysis in the context of the life cycle of a weapon system, support system, or individual piece of equipment. The following paragraphs describe fundamental analysis considerations which apply to all systems, whether they are aircraft, space, missile or communications.

System Cost Categories. The introduction of a weapon system into the Air Force inventory can be divided into three general cost categories of: (1) Development Costs, (2) Investment Costs and (3) Operations Costs (Earles, 1976:43). A breakdown of various elements of cost within these three major categories is depicted in Figure 3. The development category includes those costs in the early phase of a system

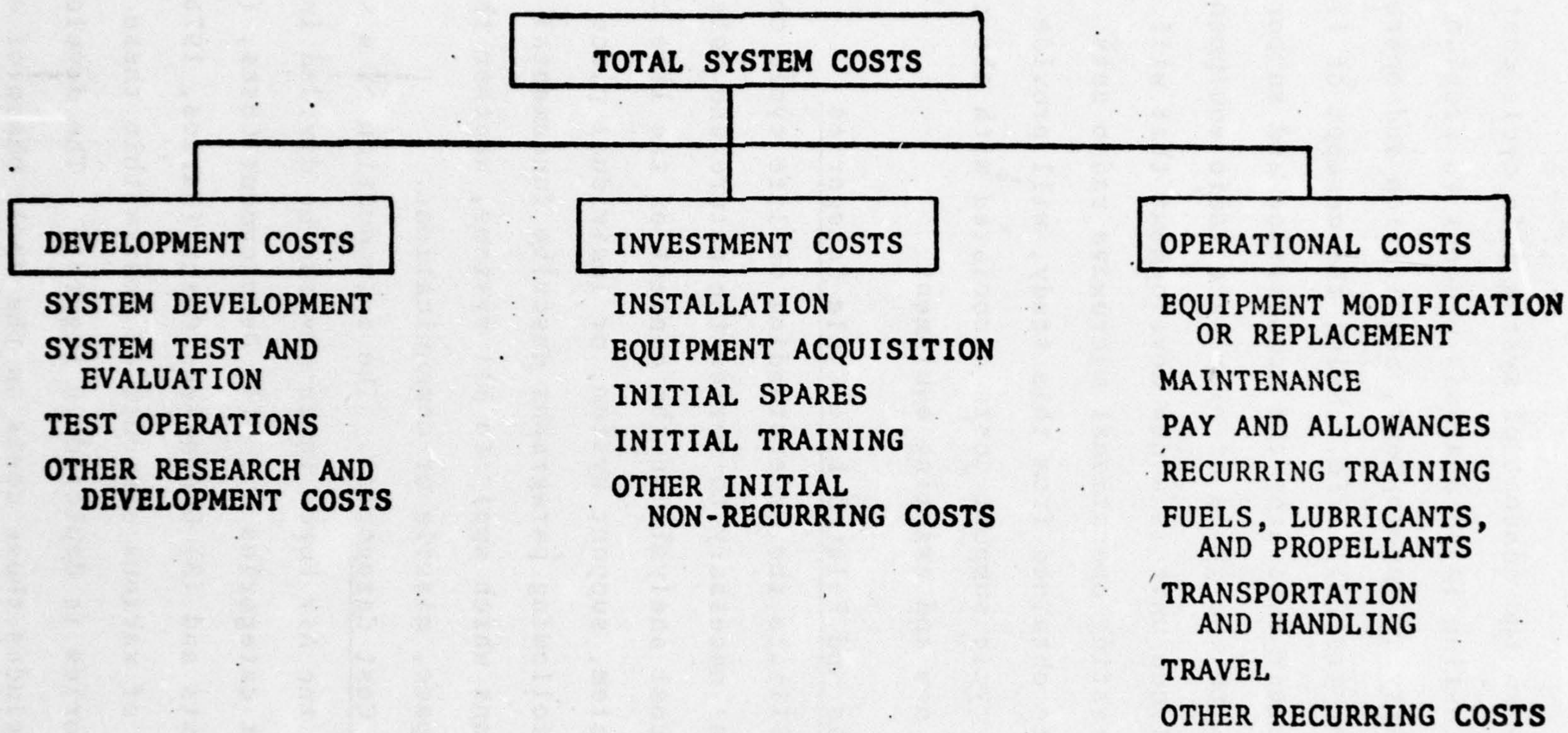

Fig. 3. Major Cost Categories "System Life Cycle"

necessary to bring that system into a state of readiness for introduction into the operational inventory. The costs associated with preliminary research studies, designs, scientific and engineering work, system prototypes, test articles, test equipment and test operations are just a few that must be included in the development category.

After the system has been developed and tested to the acceptable level of performance, the decision is made to procure the system and place it in the operational inventory. It is at this point that the costs associated with the invesment category are specified. Investment costs are those one-time outlays incurred when introducing a new system into the inventory for operational use. Initial costs such as construction or modification of facilities, acquisition of prime system equipment, support equipment, test equipment and initial spare requirements are a few examples of the non-recurring investment costs.

The third major cost category, operating costs, includes all recurring annual costs which are necessary to operate and support the new system throughout its useful life. A few major costs included in this category are personnel pay and allowances, recurring training, system maintenance, replenishing spares, materials consumption and a wide variety of indirect support costs.

The major cost categories are segregated according to three sequential time phases in the life cycle of a system. This was depicted by Fisher (see Fig. 4). He shows a time

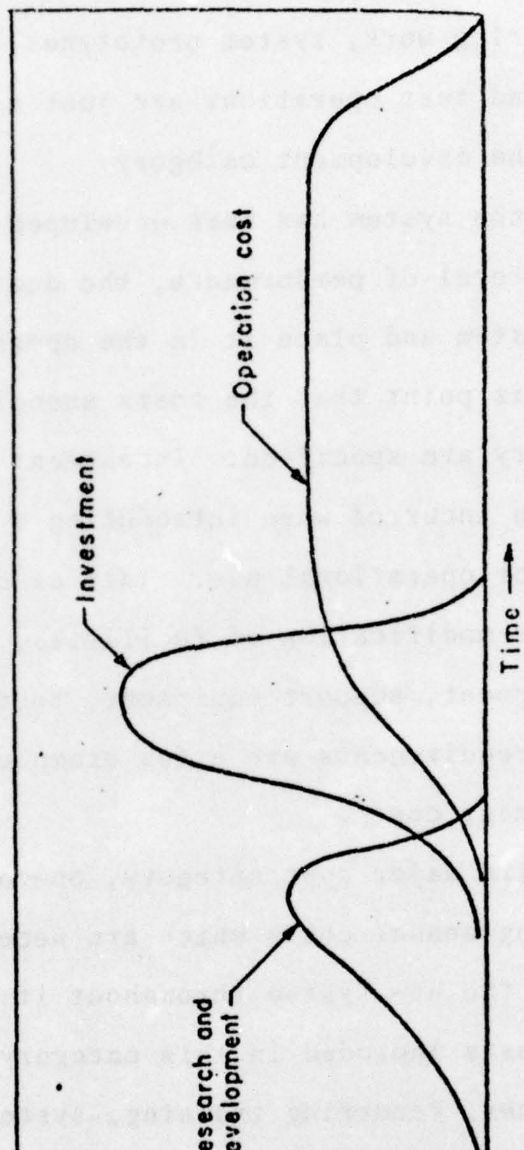

Fig. 4. System "Life Cycle" Cost Categories
(Source: Fisher, 1970:67)

phased relationship of the system costs associated with the three categories of development, investment and operation (Fisher, 1968:131). This illustration also shows an overlap between the three general cost categories. The overlap indicates that although the three categories are separate and sequential, they are not totally independent and there is interaction and interrelationships between them. Operational requirements often influence the development and investment categories and system development results will affect the operations category. These interactions and interrelationships between the general cost categories are the basic precepts behind the philosophy of Life Cycle Costing.

System Life Cycle Costs. The Department of Defense Life Cycle Costing Guide defines Life Cycle Cost of a system as the total cost to the government of acquisition and ownership of that system over its full life. It includes the cost of development, acquisition, operation, support and where applicable, disposal (LCC-3, 1973:1-1). In its strictest sense, life cycle cost is the sum of "all" costs associated with a system.

Effective life cycle cost estimating requires the understanding of the three major cost categories mentioned in the previous section, their respective subcategories, the interaction between categories and the time horizon associated with each. This then forms a useful framework from which an analyst can determine the scope of a given cost estimating problem. A more detailed list of life cycle cost categories

and subcategories is presented in Table I. Although not a complete checklist of potential cost categories, it helps to identify most required resource categories (equipment, manpower, etc.) one might encounter in a cost analysis of a system or subsystem.

Life cycle cost estimates may include only portions of the total cost, depending on the purpose of the analysis. A particular segment of life cycle cost to be emphasized is the cost of ownership of a system or piece of equipment once it enters the operational inventory. For the purposes of this study, cost of ownership refers to the relevant one-time investment costs and recurring operating costs. The recurring operating costs to be identified are the logistic costs associated with maintenance and supply support. Development costs will not be included because they are sunk costs. The scope of the study considers the life cycle support costs incurred from acquisition of the digital applique unit, modification of the analog radio sets and their respective maintenance and supply support costs over an estimated operational period of ten years.

<u>Life Cycle Cost Literature Review</u>. After a review of life cycle cost related literature, one begins to realize that the bulk of this material is addressed primarily to aircraft systems and their operating environment. There appears to be relatively little written on the application of life cycle costing techniques to fixed communications and electronics systems so the researcher was unable to find any spe-

Table I

Cost Analysis Categories for Individual Systems

I. Research and development costs

- A. System development
- B. System test and evaluation
- C. Other system costs

II. Investment costs

- A. Installations
- B. Equipment
    1. Primary mission
    2. Specialized
    3. Other
- C. Stocks
    1. Initial stock levels
    2. Equipment spares and spare parts (initial)
- D. Initial training
- E. Miscellaneous
    1. Initial transportation
    2. Initial travel
    3. Intermediate and support major command

III. Operation costs

- A. Equipment and installations replacement
    1. Primary mission equipment
    2. Specialized equipment
    3. Other equipment
    4. Installations
- B. Maintenance
    1. Primary mission equipment
    2. Specialized equipment
    3. Other equipment
    4. Installations
- C. Pay and allowances
- D. Training
- E. Fuels, lubricants and propellants
    1. Primary mission equipment
    2. Other
- F. Services and miscellaneous
    1. Transportation
    2. Travel
    3. Other (including maintenance of organizational equipment)
- G. Intermediate and support major command operation cost (only exceptionally included in cost analysis of individual systems)

(Source: Fisher, 1968:132)

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cific methodology of how to implement these concepts for the DAU/Analog FM radio communications equipment. Therefore, an assumption of this study is that the philosophy and concepts of life cycle costing, which has evolved in the aircraft cost analysis arena, can appropriately be translated into useable techniques for the fixed communication systems.

The methodology used in this thesis was to develop a cost estimating routine adapted from principles and techniques found in current use. In particular, the concepts of existing logistic support cost estimating techniques and cost models, were reviewed for the purpose of obtaining a life cycle support cost for the DAU/Analog radio equipment. Various cost estimating relationships, cost equations, and a system cost model were formulated. These were used in deriving cost estimates for the DAU/FM radio equipment. Cost sensitivity analysis was performed using the cost model. The cost model formulated for this study is a deterministic type of model combining the techniques of cost analysis into a series of mathematical equations.

Cost Models

Several attempts have been made to develop general life cycle cost models, while a great majority of the models were developed for a specific program, system or type of equipment. There appears to be a sufficient stock of cost models available, however, each cost estimating problem is unique. This generally requires modifying an existing model to re-

flect the specific application. Selecting and modifying an existing model depends not only on the system to be modeled, but also the scope of the cost estimating problem.

Cost Modeling Procedure. The Logistics Cost Analysis office at the Electronic Systems Division outlined a four step procedure as guidance in the development of a cost estimating model (Scherck, 1976:4-7). The initial step is to understand and gain knowledge of the system. The second step is to identify the significant cost elements. Step three is the creation of the cost equations and finally the development of the model. The variety of different factors that must be considered demands that cost estimating models be tailored to the system. It is apparent that knowledge of the system's life cycle phases of development, investment and operations are required. Then, depending on the scope and purpose of the cost estimating problem, more detailed understanding of the technical aspects of the equipment, maintenance concepts, support requirements and operational environment may be needed. In short, it is necessary to have a good idea of what the system is that you will attempt to model.

After this, cost elements that are determined to be relevant can be identified. Cost elements are nothing more than a classification of costs by type, such as; spares, maintenance manhours, acquisition costs and many others. The list in Table I is a useful guide in the identification of cost elements.

Once a thorough understanding of the system is achieved

and cost elements have been identified, the selection or development of an appropriate model is the next step. As was stated earlier, there are a number of different cost models in existence and exposure to a variety of models not only broadens your knowledge of models, but also helps in selecting and adapting equations that fit the particular situation.

Available Cost Models. A literature search revealed the existence of a wide variety of cost models dealing with life cycle cost or segments of life cycle cost. A recent Air Force Institute of Technology thesis, titled "A Summary and Analysis of Selected Life Cycle Costing Techniques and Models" presented a taxonomy of various life cycle cost models, their purpose and computational methodology (Dover, 1974:16-51). Dover's study defined six types of models based primarily on the use for which each model was designed. The six types are: accounting models, cost estimating relationship (CER) models, simulation models, failure free warranty models, reliability models and economic analysis models. An Aeronautical Systems Division technical report on available cost models also lists level of repair models, maintenance manpower planning models and inventory management models as separate categories in addition to those previously mentioned (Collins, 1974:6). Refer to Table II for a brief description of the types of models mentioned above.

Accounting Model. Of the several types of models identified, the accounting model was selected to estimate the radio equipment support costs of this study. The accounting

Table II

Types of Available Life Cycle Cost Models

1. Accounting Model. A set of equations which are used to aggregate components of support costs, including costs of manpower and material, to a total or subtotal of life cycle costs.

2. Economic Analysis Model. A model characterized by consideration of the time value of money, specific program schedules and the question of investing money in the near future to reduce costs in the more distant future.

3. Cost Estimating Relationship Model. An equation relating life cycle cost or some portion thereof, directly to parameters that describe the design, performance, or operating environment of a system.

4. Reliability Improvement Cost Model. An equation that reflects the cost associated with improving equipment reliability.

5. Level of Repair Analysis Model. A model that, for a given piece of equipment, determines a minimum cost maintenance policy from among a set of policy options that typically include discard at failure, repair at base and repair at depot.

6. Maintenance Manpower Planning Model. A model that determines the cost impact of alternative maintenance manpower requirements of the effects of alternative equipment designs on maintenance manpower requirements.

7. Inventory Management Model. A model that determines, for a given system, a set of spare part stock levels that is optimal in that it minimizes system spares costs or minimizes the Not Operationally Ready Supply (NORS) rate of the system.

8. Warranty Model. A model that assesses the relative costs of having the Government do in-house maintenance versus having this maintenance performed by contractors under warranty.

(Source: Collins, 1974:6,7)

model is useful for comparing and discriminating between alternatives where the relative cost difference is the desired figure of merit. The selection of the particular accounting model to be adapted for this study will be discussed in greater detail in the next section.

A cost model is a structured analog of reality. It is a representation of a physical situation which describes the relationship between elements of the process or system it is imitating (Logistics Support Cost Model User's Guide, 1975:2).

Accounting models are characterized by representing the system or process with mathematical relationships of important system parameters. The model is simply a set of mathematical equation statements describing the conditions of the system or process. Accounting models normally yield a unique set of answers or a single answer for any given set of input variable values. Performing sensitivity analysis by varying the value of a specific parameter will yield an answer within a range of values.

The development of an accounting model or the tailoring of an existing model should serve two purposes. First, the model should provide an orderly and logical way of looking at the interrelationships of the major factors of the system. Second, it should serve as a tool for sensitivity analysis, evaluating changes in total costs caused by varying important system parameters.

Rationale for Model Selection

System operating and support costs are typically greater than, and often several times greater than, the initial acquisition cost. Using a life cycle cost model is a generally accepted technique to estimate the operating and support costs that may be incurred when acquiring a given system. Estimates attained from a life cycle cost model can give the system managers and users greater visibility of resource requirements over the total life of the system. Life cycle cost estimates are prepared for a variety of purposes and several of their uses are listed below (Menker, 1975:1-1):

a. Estimate total ownership cost of proposed system.
b. Identify major operating and support cost elements.
c. Examine logistics (supply and maintenance) philosophies.
d. Conduct tradeoff studies between alternate systems or designs.
e. Evaluate equipment modification or replacement decisions.
f. Evaluate engineering change proposals.
g. Perform economic feasibility studies.

The purpose of the model developed in Chapter III is to provide a methodology to conduct cost tradeoff analyses among the alternatives of digital radio equipment for Stage III of the Digital European Backbone Program.

Logistics Support Cost Model. Various cost models were identified during this research effort by review of the literature and discussion with Air Force Systems Command and Air Force Logistics Command personnel. The accounting type model was the most frequently referenced cost estimating technique

for computing the operating and support segment of life cycle costs. Of the many accounting models available, the Air Force Logistics Support Cost Model is one of the most familiar and widely used (Dover, 1975:19). Although it has become relatively standard, it must be tailored for each new application and multiple versions of the model exist. As mentioned earlier, accounting models are basically a structured method of adding up life cycle component costs (Paulson, 1971: 12). The Logistics Support Cost Model aggregates the cost of ten subcategories of cost, each represented by a mathematical equation. The ten cost elements of the model are (Air Force Logistics Command; Logistics Support Cost Model User's Handbook, 1975):

1. Initial and replacement spares costs.
2. On-equipment maintenance costs.
3. Off-equipment maintenance costs.
4. Inventory and supply management costs.
5. Support equipment costs.
6. Training costs (personnel and equipment).
7. Management and technical data costs.
8. Facilities costs.
9. Fuel consumption costs.
10. Spare engine costs.

The logistics support cost model has been used by several program offices in the early stages of system development to estimate expected logistics support costs. It has received wide usage in source selection evaluations and design tradeoff decisions. Tailored versions of the model to fit the specific system have been used as one of the source

selection criteria on such systems as the ARC/164 UHF radio, B-1 electronic countermeasures package, F-16 aircraft, A-10 aircraft and new TACAN sets (Collins, 1976:56 and Galin, 1975:26). Contractors were supplied the model as part of the request for proposal and they were required to supply the values for the parameters in their response. The support cost model is not only used in source selection, but the early estimates obtained from contractors have been used as contractual commitments involving positive and negative incentive clauses (Stanesburg, 1976:20).

Model Selection. The researcher selected the logistics support cost model as a guide to develop the equations for the radio equipment cost relationships. Although most of the equations of the basic logistics support cost model do not reflect the radio communications situation, the concepts are similar and readily adaptable. It is also a widely used and accepted accounting model for estimating life cycle operating and support costs and has been adapted for a variety of applications as mentioned in the previous section.

Summary

This chapter discussed the need for total cost visibility of new and existing systems. System life cycle cost categories were identified and several types of cost models were listed. The chapter concluded with a discussion of the logistics support cost model.

The next chapter will identify important support factors and discuss their relationship to estimating support costs.

III. Model Formulation

Prior to describing in detail the cost equations for each element of the model a brief overview of a few important concepts and definitions is in order. Most logistic support cost models are formulated around the three following fundamental and related areas; equipment characteristics, maintenance concepts, and supply support requirements. The interaction between these three factors determines the relevant and prevailing costs associated with the operation of a system or piece of equipment. The following sections will serve to point out the relationships between the three factors and define important equipment, maintenance, and supply parameters.

Equipment Characteristics

Reliability and maintainability are the predominate equipment characteristics from which life cycle logistic support cost models are developed. According to the joint Air Force Logistics Command and Systems Command Pamphlet 400-11 they are defined as follows:

> Reliability is the probability that an item will perform a required function under specified conditions for a specified period of time. Reliability may be expressed in terms such as mean-time-between-failures (MTBF), operating time between failures, or as a decimal value.
>
> Maintainability is a characteristic of design and installation expressed as the probability that an item will be retained in or restored to a specific condition within a given period of time when the maintenance is performed according to prescribed procedures and resources.

Reliability and maintainability are expressed in terms of measurable parameters of mean-time-between-failures (MTBF) and mean-time-to-repair (MTTR), respectively. Definitions for these technical equipment parameters are (United States Department of Defense, MIL-STD-721B, 1966:5,6):

> <u>Mean-time-between-failures (MTBF)</u> for a particular interval, the total functioning life of a population of an item divided by the total number of failures within the population during the measurement interval. The definition holds for times, cycles, miles, events or other measures of life units.
>
> <u>Mean-time-to-repair (MTTR)</u> is the total corrective maintenance time divided by the total number of corrective maintenance actions during a given period of time.

Reliability is a principal equipment performance factor influencing design and life cycle support costs. It is considered the lead factor in determining other factors such as; maintenance, spares, and other support requirements. The technical equipment parameter mean-time-between-failures is used extensively in most logistics support cost models. Six of the thirteen cost element equations of the model developed in this study required the use of mean-time-between-failures as an independent variable. Determination of the expected number of failures over a projected equipment usage period is obtained using the derived values of mean-time-between-failures. The number of failures translates directly to an equal number of required maintenance actions. The technical parameter mean-time-to-repair, associated with equipment maintainability, indicates the maintenance man-hours required to repair each failure. At the same time, each repair action would generally

result in a demand on the supply system to furnish the needed or serviceable spares to correct the failure. Replenishment spares must be provided for that fraction of failures that are condemned. This briefly demonstrates how the factor of equipment characteristics influences maintenance and supply support. It can be stated that reliability and maintainability are considerations of equipment design, while maintenance and supply support are consequences of that design (Air Force Logistics Command Pamphlet, 1973:11).

The following example further illustrates the link technical equipment parameters have on life cycle maintenance and supply support costs. Consider a hypothetical piece of equipment with the following parameter values:

Mean-operating-time-between-failures (MTBF)	=	1000 Hours
Mean-time-to-repair (MTTR)	=	5 Hours
Direct Maintenance Labor Cost (DLC)	=	$10 per hour
Supply Cost/Replacement Part (SC)	=	$100 per part
Projected Operating Hours (POH)	=	100,000 Hours

<u>Life Cycle Support Cost Calculations</u>

$$\text{Number of Failures} = \frac{\text{POH}}{\text{MTBF}} = \frac{100{,}000}{1000} = 100 \text{ Failures}$$

$$\text{Total Labor Cost} = (\text{Number of Failures})\ (\text{MTTR})\ (\text{DLC})$$
$$= (100)\ (10)\ (5) = \$5{,}000$$

$$\text{Total Supply Costs} = (\text{Number of Failures})\ (\text{SC})$$
$$= (100)\ (100) = \$10{,}000$$

$$\text{Total Support Cost} = (\$5{,}000) + (\$10{,}000) = \$15{,}000$$

Maintenance Concepts

Maintenance actions are subdivided into either scheduled or unscheduled maintenance. Total maintenance requirements include those that occur on an unscheduled basis (failures) and those which are scheduled (preplanned by policy). The purpose of scheduled maintenance is to prevent failures and is often referred to as preventive maintenance. It is the performance of various prescribed routines such as; inspections, alignments, or servicing. These routines are accomplished on a periodic pre-planned interval or schedule according to established maintenance policy. As noted in the previous section, failures and therefore unscheduled maintenance requirements, are a function of equipment reliability. The probable failure intervals (MTBF) or reliability also plays a role when establishing scheduled maintenance intervals (Air Force Logistics Command Pamphlet 800-3, 1973:68).

In the Air Force the functional maintenance organization created to accomplish all scheduled and unscheduled maintenance consists of three levels of responsibility; organizational, intermediate, and depot. Each level of maintenance has an inherent cost that must be considered when establishing maintenance policy. It can be noted in the definitions to follow, how each level varies relative to responsibilities, required technical skill levels, and role in the maintenance support requirements (U. S. Air Force Regulation 66-14, 1975: 10,13).

Organizational Level Maintenance. That category of maintenance actions which is normally the responsibility of and performed by a using organization on its assigned equipment. It normally includes:

(a) Scheduled maintenance inspections; fault isolation, component removal, replacement, calibration and repairs for Communications-Electronics-Meteorological (CEM) systems and equipment.
(b) Corrosion prevention and control.
(c) Modification of material as directed.

Intermediate Level Maintenance. That category of maintenance actions which is normally the responsibility of and performed by designated maintenance activities for direct support of the using organization. Normally it is accomplished in fixed or mobile shops or by mobile teams and includes:

(a) Inspections of materiel other than aircraft, missiles or CEM end items.
(b) Repair of unserviceable parts, assemblies, sub-assemblies, and components.
(c) Modification of materiel as directed.
(d) Repair and testing of gas turbine engines and reciprocating engines.
(e) Local manufacture of critical nonavailable parts, as authorized.
(f) Test and calibration.
(g) Demilitarization and reclamation of materiel.
(h) Corrosion prevention and control.
(i) Scheduled inspection and on-equipment repair of aircraft, missiles, engines, CEM (Communications-Electronics-Meteorological), and AGE (Aerospace Ground Equipment) when greater efficiency can be attained than at the organizational level.

Depot Level Maintenance. That category of maintenance actions normally includes: inspection, test, repair, modification, alteration, modernization, conversion, overhaul, reclamation, or rebuild of parts, assemblies, sub-assemblies, components, equipment end items, and weapons systems; the manufacture of critical non-available parts; and providing technical assistance to maintenance activities. Depot level maintenance is the responsibility of and performed by designated maintenance activities, to augment stocks of serviceable materiel, and to support organizational and intermediate maintenance activities by more extensive shop facilities and equipment and personnel of higher technical skill than are normally available at the lower levels of maintenance. Depot level maintenance is normally

(Source: Fisher, 1968:132)

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accomplished in fixed shops or by dispatched teams.

The objective of maintenance is to provide operational equipment to satisfy mission requirements. Creating maintenance policies to adequately achieve this objective is the role of maintenance management. How management interprets the operational objective has a significant impact on support costs. It is important to realize that although maintenance concepts are influenced by equipment characteristics the final policies will be dictated by the management decisions of the using organization. Management can choose from a variety of different maintenance concepts when establishing maintenance policy. They must consider the amount of support necessary to accomplish scheduled and unscheduled maintenance, assign specific maintenance responsibilities to the different levels of maintenance, determine required skill levels and optimum numbers of personnel required at each level, and establish supply support requirements necessary to accomplish the maintenance objective.

Supply Support

This area influencing cost was briefly discussed in the previous sections. Supply support as a factor of cost is also a function of equipment characteristics and management decisions. Demands on the supply system; initial spares and replenishment spares are directly related to the failure rate of the equipment. Other cost considerations such as; the number of supply points, their locations and safety stock levels required to meet projected operational requirements

are management related decisions.

In summary, a logistics support cost model must represent the three areas of equipment characteristics, maintenance, and supply, their interrelationships and associated cost subcategories. Considerations must not only be given to equipment characteristics, but also to management related policies that influence the total cost.

Stage III Concepts to be Modeled

Stage III of the Digital European Backbone program consists of seventeen sites. Nine are located in England, seven in Belgium and one is in Germany. Of the seventeen sites, eight are to be attended terminal configurations. A terminal is a major transmit and receive site at which operational personnel monitor and perform required routing functions. Message information may be retransmitted to the next site, inserted for transmission, or picked off and channeled to specified users. Terminal sites require from one to three radio sets and digital applique units to perform this function. The other nine sites are regenerative repeaters designed for unattended operation. A repeater station consists of two microwave radio sets connected through two back-to-back digital applique units and its function is to retransmit message information to the next link in its line-of-site transmission path. The differences in site operational functions and geographical locations have a major influence on the maintenance and supply concepts used to support Stage III equipment. The following discussion will relate the Stage III support factors

that must be considered when formulating the support cost estimating model.

Modular Equipment Design. The FM microwave radio sets and the digital applique unit are primarily a modular design. A module is a functional assembly that is removed and replaced, as a unit, in order to restore the equipment to an operational condition. For ease of maintenance, most modules are also designed as replaceable plug-in assemblies. Modular construction enhances maintainability by making it easier to isolate a failure to a module and the mean-time-to-repair at the equipment level is reduced to a minimum with the replaceable plug-in feature. These are the principal corrective maintenance functions of organizational maintenance. Maintenance personnel at that level do not have to perform detailed circuit analysis or maintenance of the modules. Failed modules removed from the equipment are then shipped to a central intermediate maintenance facility for repair.

Reliability of most modular assemblies is relatively high. At the same time, equipment reliability is increased through the design of almost total redundancy. Each radio set actually consists of two redundant systems interfaced by a switch. During normal operations, one unit is operational while the other remains on standby. When a failure occurs on the operational unit, the standby unit is switched to the operational mode. It will be shown later how the modular design and high reliability of the equipment affect maintenance and supply support concepts. This is reflected in the maintenance policy which uses mobile maintenance teams to service

designated unmanned sites.

Maintenance Support. The maintenance concept for the European communications system encompasses the three basic levels of maintenance. However, due to geographical distribution of facilities and equipment reliability, the maintenance responsibilities are assigned in the following manner:

(1) Organizational Maintenance. The Stage III communications sites have been designated as manned or unmanned as far as organizational maintenance support is concerned. Manned sites have organizational level maintenance personnel located at the installation. They are set up to be self supporting in regard to organizational maintenance resources and each manned site is allocated necessary test equipment, spare modules and spare parts required for maintenance of the equipment installed at the site.

As the name implies, organizational maintenance personnel do not reside at unmanned sites. The high reliability and redundant features of the equipment do not require that corrective maintenance be initiated immediately upon indication of a failure. Organizational maintenance of unmanned sites is accomplished by traveling maintenance teams based at mobile maintenance support facilities. When a failure occurs at an unmanned site, a remote fault alarm system will indicate the site and a mobile maintenance team will be dispatched to make the necessary repair (T.O.31Z4-84-1, 1975: 5-1 to 5-4). The mobile support facilities include vans equipped with test equipment, spare modules and parts required

to maintain the equipment within their zone of responsibility. At the present time, the repeater stations are the only unmanned sites.

(2) Intermediate Maintenance. It is not cost effective to have the intermediate maintenance capability at each manned site. Intermediate level of repair is accomplished by a centralized intermediate maintenance facility (CIMF) located at Ramstein AFB, Germany. All modules, repairable assemblies and items beyond the capability of organizational maintenance are repaired at the intermediate maintenance facility. The decision as to whether a module should be condemned is also made at this level.

With the creation of a central intermediate maintenance facility, the role of intermediate level maintenance was expanded to pick up certain features and responsibilities of depot maintenance. Increasing the capability at the intermediate level eliminated the need for a separate organic maintenance function at depot level. As far as total maintenance capabilities are concerned, the centralized intermediate maintenance facility functions as a mini-depot combining the role of intermediate and depot maintenance at one location in Europe.

(3) Depot Responsibilities. The Sacramento Air Logistics Center, located at McClellan AFB, California is the logistics depot responsible for the communications equipment operated at the Scope Comm sites in Europe. As just mentioned, the maintenance policy does not require the depot level maintenance function. The depot may periodically contract for maintenance

of items not repairable at the European intermediate maintenance level. Because the centralized intermediate maintenance capability can repair the majority of failed modules, the need to contract for repair is very infrequent. The cost effective approach is to accumulate a stock of failed modules until it is determined economically feasible to return them to the depot for contract maintenance. Due to the random nature of this support, it will not be incorporated in the developed cost model.

Supply Support. Stock levels of spare modules are maintained at two levels. The maintenance concept requires that a specified amount of available stock be maintained at most communication sites in addition to the stock level at the host base supplies. The manned sites and mobile maintenance facilities function as forward supply points to support immediate organizational maintenance needs. Unmanned sites are not stocked, instead, the maintenance vans are equipped with a level of spares to support the unmanned site repair requirements.

Replenishment of serviceable modules is provided by host base supply units. Failed assemblies are exchanged by the organizational units for operable spares from base supply. The seventeen Stage III sites receive supply support from two host bases. One is located in England and provides supplies to the nine sites located in England. The other is in Germany and supplies the needs of the eight sites in Belgium and Germany. The host bases are also responsible for transportation

and handling of failed modules to the intermediate maintenance facility for repair.

The Cost Model

Cost Elements and Equations. Having briefly related the interaction between the three fundamental support cost factors the next step, model formulation, will identify the relevant cost elements and equations of the cost model. Keeping in mind the discussion in Chapter II about identifying cost categories, the writer was aided by referring to Table I, page 24 and the generalized Logistics Support Cost Model (Air Force Logistics Command, User's Handbook, 1975). Figure 5 depicts the investment and operations costs incorporated in the cost model. The three categories of cost that include facilities, test equipment repair, and recurring training were not considered in the model. Facilities are sunk costs, they already exist and do not require modification to accept the new equipment. Test equipment repair and recurring training are considered a part of the overhead cost for general support that is common for several systems and not readily estimated. Only the initial investment costs of test equipment and training are represented by the model.

The complete model is the summation of thirteen separate cost element equations and requires 54 data elements. The data elements vary from standard factors obtained from government sources, equipment oriented variables, to communication system maintenance and supply support variables. A complete summarized listing of the equations and alphabetical listing

INVESTMENT COSTS (Non-Recurring)		OPERATIONS COSTS (Logistic-Recurring)		
Equipment Acquisition Modification		Maintenance Scheduled Unscheduled Organizational Intermediate		CE1 = Acquisition and/or Modification Costs CE2 = Initial Spares Cost
Stock (Initial)	+		=	CE3 = Non-Recoverable Item Costs
Technical Documentation		Replacement Spares		CE4 = Unscheduled Organizational Maintenance Costs
Test Equipment		Travel		CE5 = Unscheduled Intermediate Maintenance Costs
Training (Initial)		Transportation and Handling		CE6 = Scheduled Organizational Maintenance Labor Cost
				CE7 = Scheduled Organizational Maintenance Indirect Travel Costs
				CE8 = Unscheduled Organizational Maintenance Indirect Travel Costs
				CE9 = Maintenance Reporting Costs
				CE10= Technical Data Costs
				CE11= Inventory Management Costs
				CE12= Test Equipment
				CE13= Training Costs

Fig. 5. Relevant Investment and Operations Subcategories Incorporated in Cost Model

of the data elements with definitions is presented in Appendix A. The discussion that follows defines each cost element, presents the mathematical equations representing each element, and defines the variable name of each data element used in the model.

Cost Element 1: Acquisition and/or Modification Cost. The initial element of cost computes the dollars associated with the procurement of the number of required pieces of new equipment. It also computes the total system cost of modifications to existing radio equipment.

Equation:

$$CE1 = (NO)\ (AQMOD)$$

Variables Defined:

CE1 = Acquisition and/or Modification Costs.

NO = Total number of units to be installed or the number of modifications required.

AQMOD = The unit acquisition cost for quantity procured and/or the modification cost per piece of equipment modified.

Cost Element 2: Initial Spare, Recoverable Items. The second element of cost determines the acquisition costs associated with initial spares to sufficiently stock the individual communication sites and multiple host base supply points. Recoverable spares are those components that are repairable and then returned to the inventory of serviceable stock. Initial stock levels are created to have readily available spares to replace those that may be in the supply system pipeline. Pipeline is defined as the period of time a recoverable item spends in a state of repair, transportation or handling

and is not on hand at the using site. The equation considers two distinct pipelines. The first is the time from initiation of a site order to the receipt of the component from the host base supply. The second includes the time a failed item is shipped to the intermediate maintenance repair facility, repaired, and returned to the base supply stock of serviceable parts.

Equation:

$$CE2 = NSV \sum_{i=1}^{N} (SSTK_i)(UP_i) + NBS \sum_{i=1}^{N} (BSTK_i)(UP_i)$$

Variables Defined:

CE2 = Cost of Initial Spares

N = The number of different components to be stocked.

i = The subscript identifying each component.

NSV = The number of sites (also includes Vans) maintaining stock level of spares.

$SSTK_i$ = The site stock level of the ith component.

NBS = The number of host base supply points.

$BSTK_i$ = The base stock level of the ith component.

UP_i = The unit price of the ith component.

The first term $[NSV \sum_{i=1}^{N} (SSTK_i)(UP_i)]$ is the cost of initial spares required at the communications sites to account for the base supply pipeline. The stock level for the ith component ($SSTK_i$), is based on the probability of satisfying a demand that is at least equal to an established maintenance policy confidence level for a desired availability of parts. The value of $SSTK_i$ is a function of the mean demand which is de-

termined from the expected failure rate multiplied by the base supply pipeline time. The calculation of $SSTK_i$ is derived as follows:

$$SDMEAN_i = \left[\frac{(AMH)(QPA_i)}{(MTBF_i)}\right]\left[\frac{BSPT}{NSV}\right]$$

Variables Defined:

$SDMEAN_i$ = Mean demand for the ith component at communications site level.

AMH = Average monthly operating hours per piece of equipment multiplied by the number of units to give system total operating hours per month.

QPA_i = Quantity per application of the ith component. The maximum number of like components installed in a single unit or radio set.

$MTBF_i$ = Expected mean-time-between-failures of the ith component during the projected usage period (Expressed in operating hours).

NSV = The number of sites (also includes Vans) maintaining stock level of spares.

BSPT = Base supply pipeline time. This is the average base supply cycle time in response to a site initiated parts request.

The term $\left[\frac{(AMH)(QPA_i)}{(MTBF_i)}\right]$ is used in several of the cost element equations. This term is dependent on the reliability parameter $(MTBF_i)$ of each component. The calculation of this expression provides the number of failures of the ith component expected per month from all operational equipment within the system.

Using the value derived for $SDMEAN_i$, the minimum value of $SSTK_i$ must be found using the next expression.

$$\sum_{n=0}^{SSTK_i} \frac{(e^{-SDMEAN_i})(SDMEAN_i)^n}{n!} \geq CONF$$

Variables Defined:

$SSTK_i$ = The site stock level of the ith component.

$SDMEAN_i$ = Mean demand for the ith component at communications site level.

CONF = The confidence level factor established by maintenance policy for a desired stock availability.

The above expression is computed for each value of n until the minimum value that still satisfies the equation is reached. That minimum value of $SSTK_i$ is then used in the cost equation for CE2.

The same calculations are used to determine the initial base supply stock, except the pipeline time is now the repair cycle time to intermediate maintenance and back. The expressions to compute base stock level then become:

$$BDMEAN_i = \left[\frac{(AMH)(QPA_i)}{(MTBF_i)(NBS)}\right]\left[CIPT\right]$$

$$\sum_{n=0}^{BSTK_i} \frac{(e^{-BDMEAN_i})(BDMEAN_i)^n}{n!} \geq CONF$$

Variables Defined:

$BDMEAN_i$ = Mean demand for the ith component at base supply level.

AMH = Average monthly operating hours per piece of equipment multiplied by the number of units to give system total operating hours per month.

QPA_i = Quantity per application of the ith component. The maximum number of like components installed in a single unit or radio set.

NBS = The number of host base supply points.

$MTBF_i$ = Expected mean-time-between-failures of the ith component during the projected usage period (Expressed in operating hours).

CIPT = Central intermediate maintenance repair pipeline time.

$BSTK_i$ = Base stock level of the ith component.

CONF = The confidence level factor for a desired stock availability.

Cost Element 3: Non-Recoverable Item Costs. Non-recoverable items are those components replaced and discarded during a corrective maintenance action. The third element considers the costs associated with the replenishment of non-recoverable (condemned) components, piece part and material consumption expected during the life cycle of the equipment. Condemnation of a repairable item occurs when it is determined that repair is either technically or economically infeasible. The cost of replenishment parts is assumed to be the same as the initial spares cost.

Equation:

$$CE3 = 12\ PIUP \sum_{i=1}^{N} \left[\frac{(AMH)(QPA)}{(MTBF_i)}\right] [UP_i] \left[(COND_i)(NRTS_i) + (PCF)(NRTS_i - COND_i)\right]$$

Variables Defined:

CE3 = Cost of non-recoverable items.

PIUP = The projected inventory usage period (expressed in years).

AMH = Average monthly operating hours per piece of equipment multiplied by the number of units to give system total operating hours per month.

QPA_i = Quantity per application of the ith component. The maximum number of like components installed in a single unit or radio set.

$MTBF_i$ = Expected mean-time-between-failures of the ith component during the projected usage period (Expressed in operating hours).

UP_i = The unit price of the ith module or component.

$COND_i$ = Condemnation of the ith component, expressed as a decimal fraction of the failures and removals of the ith component.

PCF = Parts consumption cost factor, expressed as a fraction of the recoverable parts costs (PCF = .05; Source: Defense Communications Agency Circular 600-60-1, 1972:22-4).

$NRTS_i$ = Fraction of failure of ith module/item which is transferred to intermediate maintenance facility for repair (Not repairable this station).

The term $\frac{(AMH)(QPA_i)}{(MTBF_i)}$ computes the number of failures of the ith component expected per month from all operational equipment within the system. Multiplying the number of failures by $COND_i$ provides the number of components that are condemned and must be replenished. The second term $[(PCF)(NRTS_i)]$ is an estimate of piece parts and materials consumed during repair of recoverable components. PCFs is a cost estimating relationship derived from historical costs.

<u>Cost Element 4: Unscheduled Maintenance/Organization Level</u>. The fourth cost element considers the cost associated with direct labor expended at the organization maintenance level to correct failures attributed to the ith item or module.

Equation:

$$CE4 = 12\ PIUP \sum_{i=1}^{N} \left[\frac{(AMH)(QPA_i)}{(MTBF_i)}\right] [(OTTR_i)(OLR) + (OMMH_i)(OLR)(RTS_i)]$$

Variables Defined:

CE4 = Unscheduled maintenance/organizational level.

PIUP = The projected inventory usage period (Expressed in years).

AMH = Average monthly operating hours per piece of equipment multiplied by the number of units to give system total operating hours per month.

QPA_i = Quantity per application of the ith component. The maximum number of like components installed in a single unit or radio set.

$MTBF_i$ = Expected mean-time-between-failures of the ith component during the projected usage period (Expressed in operating hours).

$OTTR_i$ = Organizational time to repair is the average manhours per failure of the ith module/component to test, remove, replace and realign to place the equipment into operable condition.

OLR = Organizational labor rate of maintenance technician (OLR = \$13.10, Source: Logistic Support Cost User's Guide, 1975:2-4).

OMMH = The average number of organizational shop maintenance manhours expended for site repair of the ith module/item.

RTS_i = Fraction of removals of the ith module/item which are repaired at the organizational level and returned to service (Repair this station).

The first term in the equation computes the cost of organizational labor expected for the repair of the major piece of equipment. This term is the direct labor cost to isolate the failed module, remove and replace with a serviceable module and perform any needed alignments to reinstate the prime equipment to an operational state. The second term in the expression computes organizational labor cost for repair of those modules or items identified as repairable at that level.

<u>Cost Element 5: Unscheduled Maintenance/Intermediate Level</u>. The fifth cost element calculates the dollars associated with repair of modules/items at the intermediate level

of maintenance. Two factors are considered. The first is the direct intermediate level labor cost to repair the ith module/item. The second cost is transportation and handling expenses of each ith item/module between host supply bases and the intermediate maintenance facility.

Equation:

$$CE5 = 12\ PIUP \sum_{i=1}^{N} \left[\frac{(AMH)(QPA_i)}{(MTBF_i)} \right] [(CMMH_i)(CLR)(NRTS_i) + (NRTS_i)(RTT_i)]$$

Variables Defined:

CE5 = Unscheduled maintenance/Intermediate level.

PIUP = The projected inventory usage period (Expressed in years).

$COND_i$ = Condemnation of the ith component, expressed as a decimal fraction of the failures and removals of the ith component.

AMH = Average monthly operating hours per piece of equipment multiplied by the number of units to give system total operating hours per month.

QPA_i = Quantity per application of the ith component. The maximum number of like components installed in a single unit or radio set.

$CMMH_i$ = The expected mean number of intermediate maintenance manhours expended per repair of the ith module/item.

CLR = The direct labor rate of the central intermediate maintenance facility repair technician.

$NRTS_i$ = Fraction of failures of ith module/item which are transferred to intermediate maintenance for repair (Not repairable this station).

RTT_i = The average round trip transportation cost to ship the ith module to CIMF for repair and return to host base supply.

Cost Element 6: Scheduled Maintenance/Direct Labor Cost. The sixth element of cost to be considered is the dollars associated with the organizational maintenance man-hours expended to accomplish the scheduled maintenance requirements. This cost element assumes that all scheduled maintenance routines and time intervals are the same for equipment located at manned and unmanned sites. It computes the direct labor cost to perform the jth scheduled maintenance routine for all installed or to be installed operation equipment.

Equation:

$$CE6 = 12 \sum_{j=1}^{L} \left[\frac{PIUP}{SMI_j}\right] (SMH_j)(NO)(OLR)$$

Variables Defined:

CE6 = Scheduled maintenance/direct labor cost.

PIUP = The projected inventory usage period (Expressed in years).

j = The subscript denoting a specific scheduled maintenance routine.

L = The number of different schedules maintenance routines.

SMI_j = The established interval between the jth scheduled maintenance routine (Expressed in months or fraction of a month).

SMH_j = The average man-hours required to perform the jth scheduled maintenance routine.

NO = Total number of units in system to receive scheduled maintenance.

OLR = Organizational labor rate of maintenance technician (OLR = $13.10; Source: Logistics Support Cost User's Guide, 1975:2-4).

The basic term $\left[\frac{PIUP}{SMI_j}\right]$ provides the total number of times the

jth routine will be accomplished in the projected usage period. The remaining calculation is straightforward and is simply:

$$\begin{bmatrix}\text{Number of}\\ \text{Times Routine}\\ \text{is Performed}\end{bmatrix}\begin{bmatrix}\text{Average Time}\\ \text{To Perform}\end{bmatrix}\begin{bmatrix}\text{Number}\\ \text{of Units}\end{bmatrix}\begin{bmatrix}\text{Cost}\\ \text{per}\\ \text{Hour}\end{bmatrix} = \begin{matrix}\text{Total Direct}\\ \text{Labor Cost to}\\ \text{Perform Scheduled}\\ \text{Maintenance}\end{matrix}$$

Cost Element 7: Scheduled Maintenance/Indirect Cost (Unmanned Sites). A fraction of the equipment requiring scheduled maintenance are located in unmanned sites. Mobile maintenance teams servicing these unmanned sites operate from a mobile maintenance facility. The travel time and vehicle expense are indirect costs associated with the requirement to perform scheduled maintenance at these remote locations. The seventh element computes the indirect costs of organizational labor travel time and vehicle costs incurred to complete a round trip between the home facility and unmanned sites.

Equation:

$$CE7 = 12 \sum_{j=1}^{L} \left[\frac{PIUP}{SMI_j}\right] [(MTT)(2)(OLR) + (NML)(CFM)][UMF]$$

Variables Defined:

CE7 = Scheduled maintenance/indirect cost (Unmanned sites).

PIUP = The projected inventory usage period (Expressed in years).

j = The subscript denoting a specific scheduled maintenance routine.

L = The number of different scheduled maintenance routines.

SMI_j = The established interval between the jth scheduled maintenance routine (Expressed in months or fraction of a month).

MTT = Mean travel time to complete round trip.

NML = Average number of miles traveled to complete round trip.

CFM = Vehicle Cost Factor per mile traveled ($0.16 per mile, Source: Defense Communications Agency Circular, 1972:24-39).

UMF = Decimal Fraction of unmanned sites to total number of sites.

OLR = Organizational labor rate of maintenance technician (OLR = $13.10, Source: Logistics Support User's Guide, 1975:2-4).

The term $\left[12\frac{(PIUP)}{(SMI_j)}\right]$ [UMF] provides the number of times the jth scheduled maintenance routine is expected to be performed at unmanned locations over the projected time period. This equates to the number of trips mobile maintenance teams must make. The next two terms multiplied by the above expression computes indirect labor and vehicle costs respectively.

<u>Cost Element 8: Unscheduled Maintenance/Indirect Costs (Unmanned Sites)</u>. The eighth cost element is very similar to CE7. However in this case it considers the indirect costs of travel time and vehicle expenses for the trips required to respond to unscheduled maintenance requirements at the unmanned locations.

Equation:

$$CE8 = 12\ PIUP \sum_{j=1}^{N} \left[\frac{(AMH)(QPA_i)}{(MTBF_i)}\right] [(MTT)(2)(OLR) + (NML)(CFM)][UMF]$$

Variables Defined:

CE8 = Unscheduled Maintenance/Indirect Costs (Unmanned Sites).

PIUP = Projected inventory usage period (Expressed in years).

AMH = Average monthly operating hours per piece of equipment multiplied by the number of units to give system total operating hours per month.

QPA_i = Quantity per application of the ith component. The maximum number of like components installed in a single unit or radio set.

$MTBF_i$ = Expected mean-time-between-failures of the ith component during the projected usage period (Expressed in operating hours).

MTT = Mean travel time to complete round trip.

NML = Average number of miles traveled to complete round trip.

CFM = Vehicle Cost Factor per mile traveled ($0.16 per mile, Source: Defense Communications Agency Circular, 1972:24-39).

UMF = Decimal Fraction of unmanned sites to total number of sites.

OLR = Organizational Labor rate of maintenance technician (OLR = $13.10, Source: Logistics Support User's Guide, 1975:2-4).

A basic assumption required in the use of this expression is that the unmanned sites will have a proportional share of the failures.

<u>Cost Element 9: Maintenance Reporting</u>. The ninth element of cost estimates the cost associated with the direct labor expended by maintenance personnel to complete a variety of maintenance and supply support forms and paperwork. The Air Force Maintenance Data Collection System (AFM 66-1) requires that all scheduled and unscheduled maintenance performed be documented. In addition, maintenance personnel may complete supply requisition and transportation forms following most maintenance actions.

Equation:

$$CE9 = 12\ (PIUP)(OLR) \sum_{j=1}^{N} \left[\frac{(AMH)(QPA_i)}{(MTBF_i)}\right] [ART] + \sum_{j=1}^{L} \left[\frac{(.1)(ART)}{SMI_j}\right]$$

Variables Defined:

CE9 = Maintenance Reporting.

PIUP = Projected inventory usage period (Expressed in years).

OLR = Organizational labor rate of maintenance technician (OLR = $13.10; Source: Logistics Support Cost User's Guide, 1975:2-4).

AMH = Average monthly operating hours per piece of equipment multiplied by the number of units to give system total operating hours per month.

QPA_i = Quantity per application of the ith component. The maximum number of like components installed in a single unit or radio set.

$MTBF_i$ = Expected mean-time-between-failures of the ith component during the projected usage period (Expressed in operating hours).

ART = Average reporting time (ART = .65 hour; Source: Logistics Support Cost User's Guide, 1975:2-2).

SMI_j = The established interval between the jth scheduled maintenance routine (Expressed in months or fraction of a month).

The expression $\left[\frac{(AMH)(QPA_i)}{(MTBF_i)}\right]$ [ART] provides the estimate of time to document unscheduled (failure reporting) maintenance. The second term, $\left[\frac{(.1)(ART)}{SMI_j}\right]$ provides the time estimate to complete scheduled maintenance forms. Scheduled maintenance reporting does not require as much time to document, that is the reason for the .1(ART) factor.

<u>Cost Element 10: Technical Data Costs.</u> This next element of cost estimates the dollars associated with initial acquisition of technical publication or major revisions of

existing publications. This includes the cost of technical orders, manuals, and repair instructions required at organizational and intermediate maintenance levels.

Equation:

$$CE10 = TD(TO + TI)$$

Variables Defined:

CE10 = Cost of Technical Data.

TD = Average cost per original page of technical documentation (S = \$220.00/page, Source: Logistics Support Cost Model User's Guide, 1975:2-2).

TO = Estimated number of pages of organizational technical documentation required to maintain the equipment.

TI = Estimated number of pages of intermediate technical documentation required to maintain the equipment.

<u>Cost Element 11: Inventory Management Costs</u>. The next element of cost to be considered is the new item inventory management costs expected over the life cycle of the equipment. This equation computes initial and recurring supply management costs of the number of new items entering the government active inventory.

Equation:

$$CE11 = NNM[IMC + (PIUP)(RMC)]$$

Variables Defined:

CE11 = Inventory Management Costs.

NNM = Number of new modules/items.

IMC = Initial management cost to introduce a new item of supply into the Air Force inventory (\$46.60/item, Source: Logistic Support Cost User's Guide, 1975: 2-1).

RMC = Recurring management cost to maintain an item in the active Air Force inventory ($104.20/item/year, Source: Logistic Support User's Guide, 1975:2-1).

Cost Element 12: Test Equipment and Support Equipment Costs. The twelfth element considers the cost to acquire test and support equipment required to perform organizational and intermediate maintenance.

Equation:

$$CE12 = NSV(COTE) + CISE$$

Variables Defined:

CE12 = Cost of test equipment, support or specialized equipment.

NSV = The number of sites and mobile vans requiring test equipment.

COTE = Test equipment cost estimate per site for organizational maintenance requirements.

CISE = Cost of test and support equipment for intermediate maintenance requirements.

Cost Element 13: Training Costs. The thirteenth and final element of cost considers the costs associated with initial training requirements. Contractor costs to train a cadre of personnel to make up a traveling training team; plus the costs to accomplish training of maintenance personnel in the field are the predominate training costs.

Equation:

$$CE13 = THR[CCTH + (NPT)(TCH)] + OTHR[6(CMIH) + (ONPT)(OLR)]$$

Variables Defined:

CE13 = Initial training costs.

THR = Number of contractor training hours required.

CCTH = Contractor cost per training hour.

NPT = Number of personnel receiving contractor training.

TCH = Trainee cost per hour.

OTHR = Organizational level training hours required.

CMIH = Mobile instructor cost per hour.

ONPT = Number of organizational level personnel receiving training.

OLR = Organizational labor rate of maintenance technician (OLR = $13.10; Source: Logistics Support Cost User's Guide, 1975:2-4).

The first term of the expression computes the cost of the Type I, contractor training of the mobile instructors. The second term of the expression computes the cost of the mobile training team in the field training organization maintenance personnel.

Computer Model. The thirteen cost elements and their associated equations represent the relevant costs for the fixed communications equipment of this research study. The analytical accounting model provides the framework of mathematical relationships developed to compute and evaluate the life cycle support costs. Although the equations are straight forward mathematical expressions they do require a moderate amount of data, a great deal of repetitous and time consuming calculations to exercise the model. Therefore the model was programmed and run on the Aeronautical Systems Division computer. The computer language utilized was FORTRAN IV and the program was run in the batch mode using punched cards.

Model Outputs. The computer model was programmed to provide several outputs. Incremental costs were broken out to

reflect their contribution to the total cost. The available outputs are as follows:

a. Cost element subtotals provides an individual cost figure associated with each cost element (CE1 thru CE13).

b. The total cost estimate is the summation of all thirteen cost elements.

c. Intermediate maintenance direct labor costs associated with repair of recoverable components is an output.

d. Transportation and handling costs of all recoverable components turned into intermediate maintenance is another available output.

e. Scheduled maintenance costs of unmanned sites were broken out as direct labor, travel and vehicle costs.

f. Unscheduled maintenance costs of unmanned sites were broken out as direct labor, travel and vehicle costs.

g. Total cost of scheduled maintenance at manned and unmanned sites to include direct and indirect costs was computed.

h. Total cost of unscheduled maintenance was computed.

i. Total cost of all maintenance at the organizational and intermediate levels is also an available output.

Summary

Chapter III discussed the development of an accounting cost model for the Stage III communications equipment. Three factors were identified as predominate parameters in most support cost models. Equipment characteristics, maintenance,and supply support relationships must be integrated into the development of logistics support cost models. The discussion then pointed out how these three basic factors are reflected in the Stage III communications system operation. The writer then defined and described the thirteen cost element equations comprising the model. Finally, the use of a computerized version of the model was discussed.

IV. Model Results

The purpose of this chapter is to use the previously developed cost model to obtain life cycle support cost estimates for the combined operation of the digital applique unit and the existing FM microwave radio set equipment. Initial discussion will deal with the data required to exercise the model. Cost model results will be obtained and sensitivity analysis performed using the model to illustrate cost changes due to a change in selected model parameters. The cost model will also be exercised to demonstrate its utility in a potential cost tradeoff example with an alternative digital radio set.

Model Data Requirements

Equipment First Line Unit Data. Several equations of the model are dependent on parameter values associated with the equipment's identifiable first line units. First line units are defined as (Air Force Logistics Command, LSC Model User's Handbook, 1975:1-1):

> A first line unit is the first level of assembly below the system level, that is carried as a line item of supply at base level and is usually the highest level of assembly that is removable and replaced, as a unit, on a system or subsystem in order to return the equipment to an operational condition.

The first line units of the digital applique unit (DAU) consist of twenty modules that are listed in Table III. Typical data requirements at this equipment component level include such parameters as mean time between failures, mean

Table III
Digital Applique Unit Plug-In Modules

Transmit Unit	Failures/10^6 Hours
1 Power Supply	50.0000
2 Power Status	1.4575
3 Transmit Timing	13.3803
4 Transmit Control	12.2716
5 Transmit Register	11.0430
6 Transmit Interface	4.5815
7 Data Input	3.3355
8 Transmit Clock	3.9395
9 Baseband Modulator	5.8965
10 Transmit Switch	7.1085
Receive Unit	
11 Power Supply	50.0000
12 Power Status	1.4575
13 Baseband Demodulator	23.6873
14 Receive Clock/Output	22.0803
15 Receive Timing	17.8343
16 Receive Control	13.3662
17 Receive Register	6.3357
18 Receive Interface	5.1528
19 Receive Switch	9.0958
20 Performance Monitor	5.4743

(Source: Jessen, F. A. DAU Technical Report, 1975:199)

time to repair, condemnation percentage and first line unit (module) price. Because the DAU is a new development, operational data on the individual modules is not available. Therefore, most data inputs for the DAU are results of the prototype development project. The principal data sources for the DAU were the final technical report of the prototype development project and the Rome Air Development Center project engineers. The key reliability parameter mean time between failures (MTBF) listed in Table III are results of engineering estimates and do not reflect DAU operational results.

On the other hand, the FM radio equipment has been in the Air Force operational inventory for at least three years. Most of the required data at the first line unit level was obtained from actual maintenance data collected on the operational system. Within the maintenance data collection system, the first line units are given Work Unit Codes (WUC) to identify a specific component within the assembly. It is at the WUC level that maintenance data is collected and maintained. For the purposes of this study, thirty work unit codes and their associated data were used to compute the estimate of the FM radio sets life cycle support costs. Table IV identifies the work unit codes of the radio sets. Although there are more than 30 codes listed in the table, some codes were not used because they identify structural parts that are not subject to failure or some codes did not have failure data at this time. The primary sources of FM radio

Table IV

FM Radio Set Work Unit Codes/Modules

T.O. 31Z4-84-06

Microwave Radio Set LC-8D

Work Unit Code	
AGOOO	MICROWAVE RADIO SET LC-8D (PHILCO-FORD)
AGAOO	TWT Power Supply 398-12013-1
AGAAO	Printed Circuit Board Assembly A3 859519-1
AGABO	Printed Circuit Board Assembly A4 859520-1
AGACO	Printed Circuit Board Assembly A5 859521-1
AGADO	Printed Circuit Board Assembly A6 859522-1
AGAEO	Printed Circuit Board Assembly A7 859523-1
AGAFO	Printed Circuit Board Assembly A8 859524-1
AGAGO	Printed Circuit Board Assembly A9 859525-1
AGAHO	Filter Assembly A10 859849-0
AGAJO	Support Bracket and Relay Assembly 1-859849-3
AGAKO	Bracket Assembly 3-859849-1
AGALO	Terminal Board Assembly 3-859849-4
AGAMO	Back Panel Assembly 1-859819-8
AGBOO	LOW VOLTAGE POWER SUPPLY 398-13615-1
AGBAO	Power Supply 4-859815-8
AGBAA	Front Panel Assembly 4-859815-7
AGBAB	Trimpot Assembly Support 4-859815-9
AGBAC	Printed Circuit Board ASsembly 859869-1
AGBAD	Printed Circuit Board and Heatsink Subassembly 4-859815-2
AGBAE	Transformer and Heatsink Bracket Assembly 859957-1
AGBAF	Printed Circuit Board and Heatsink Subassembly 4-859815-3
AGBAG	Printed Circuit Board and Heatsink Subassembly 4-859815-2
AGCOO	IF AMPLIFIER MODULE 368-43488-1
AGDOO	IF FILTER MODULE 398-12067-4
AGEOO	LIMITER DISCRIMINATOR MODULE 398-11478-10
AGFOO	TERMINAL FILTER MODULE 368-43020-11
AGGOO	ADDER MODULE 368-42020-12

Table IV (Continued)

Work Unit Code	
AGOOO	MICROWAVE RADIO SET LC-8D (PHILCO-FORD-CONTINUED)
AGHOO	DEVIATOR MODULE 398-13665-1
AGJOO	AFC MODULE 368-42098-3
AGKOO	ALARM AMPLIFIER A MODULE 398-13579-2
AGLOO	ALARM AMPLIFIER B MODULE 398-13579-3
AGMOO	TERMINAL FILTER MODULE 368-43028-12
AGNOO	NOISE AMPLIFIER MODULE 368-43018-1
AGPOO	DUAL PILOT TONE DETECTOR MODULE 368-43035-1
AGQOO	BASEBAND COMBINER MODULE 398-12846-1
AGROO	RF APNEL ASSEMBLY 398-13341-1
AGRAO	Waveguide Shutter Assembly 398-13036-1
AGRBO	Preamplifier Module 398-12215-1
AGRCO	Traveling Wave Tube 394-1027-3 HS→COND
AGRDO	Up Converter Amplifier Module 398-13698-1
AGSOO	DOOR ASSEMBLY 398-13274-1
AGSAO	Door Subassembly 398-13302-1
AGTOO	PRIMARY FILTER ASSEMBLY 398-13805-1
AGUPP	RACK ASSEMBLY 398-13273-2
AGVOO	CABLE ASSEMBLIES

data were Headquarters European Communications Area and Sacramento Air Logistics Center.

Input Data Base. Data requirements for the cost model consists of standard Air Force cost factors, contractor estimates, engineering estimates, maintenance data system values and estimates of experts in the field. Table V lists the cost model constants and standard input values for both the DAU and FM radio. Tables VI and VII list the first line unit (module/WUC) variable values for the DAU and FM radio set respectively.

Maintenance data for the FM radio equipment operations were supplied at the organizational level but were unavailable at the intermediate level. When maintenance analysis personnel attempted to retrieve central intermediate maintenance data from their information system, they discovered it had either been entered incorrectly or had been inadvertently dumped. They stated it would probably take several months to correct the situation. Therefore, estimates were obtained for the values of mean time to repair at the intermediate maintenance level and condemnation rates of modular electronics equipment. The estimates of these two values were provided by the Ground Communications-Electronics-Meteorological Technical Systems Division (Reliability and Engineering Branch) of the Sacramento Air Logistics Center. This center is responsible for logistics support of the FM analog radios operated in Europe and all similar equipment within the Air Force operational inventory. The value of condemna-

Table V

Input Values for Cost Model Parameters
(All Costs are in 1976 Dollars)

Input Parameter *		Description	Digital Applique Unit	FM Radio Set
AHR	:	Average Monthly Operating Hours	720	720
ART	:	Average Maintenance Reporting Time	.65	.65
AQMOD	:	Unit Acquisition and/or Modification Cost	45462 (a)	3000 (a)
BSPT	:	Base Supply Pipeline Time	.50	.50
CCTH	:	Contractor Cost per Training Hour	245	0 (b)
CFM	:	Vehicle Cost Factor per Mile	.16	.16
CISE	:	Central Maintenance Special Equipment	118170 (a)	0
CIPT	:	Central Maintenance Pipeline Time	1.0	1.0
CLR	:	Central Maintenance Labor Rate	18.05	18.05
CMIH	:	Mobile Instructor Cost per Hour	15	0 (b)
CONF	:	Stock Level Confidence Factor	.98	.98
COTE	:	Cost of Site Test Equipment	2665 (a)	0 (b)
CPP	:	Transportation and Packaging Cost per lb.	.53	.53
IMC	:	Initial Inventory Management Cost	104.20	104.20
MTT	:	Mean Round Trip Travel Time	5.0	5.0
N	:	Number of Modules/Items	20	30
L	:	Number of Scheduled Maintenance Routine	6	9
NBS	:	Number of Base Supply Points	2	2
NML	:	Average Number of Miles	115	115
NNM	:	Number of New Modules	20	30
NPT	:	Number of Personnel Trained	5	0 (b)

Table V (Continued)

Input Parameter*		Description	Digital Applique Unit	FM Radio Set
NO	:	Number of Units to be Installed or Modified	34	34
NSV	:	Number of Sites and Vans Maintaining Stock	14	14
OLR	:	Organizational Labor Rate	13.10	13.10
ONPT	:	Number of Organizational Level Personnel Trained	60	0 (b)
OTHR	:	Number of Organizational Training Hours Required	80	0 (b)
PCF	:	Parts Consumption Cost Factor	.05	.05 (b)
PIUP	:	Projected Inventory Usage Period	10	10
RMC	:	Recurring Management Cost	40.90	40.90
TCH	:	Trainee Cost per Hour	15	0 (b)
TD	:	Technical Documentation	220	220
THR	:	Training Hours Required	120	0 (b)
TI	:	Number of Pages of Published Technical Instructions	200	50
TO	:	Number of Pages of Published Technical Orders	750	50
UMF	:	Fraction of Unmanned Sites	.475	.475

* Reference Appendix A for sources of most parameter values.

(a) Cost provided to Program Office from prototype development contractor.

(b) Values are zero because of sunk cost or parameter is not applicable to FM radio equipment.

Table VI

Digital Applique Unit Cost Model Equipment Variables/Input Values

N	QPA	UP	MTBF	OTTR	CMMH	RTS	NRTS	COND
1	1.	300.00	20000.	.50	6.00	0.00	1.00	.01
2	2.	150.00	687106.	.50	6.00	0.00	1.00	.01
3	2.	300.00	74776.	.50	6.00	0.00	1.00	.01
4	2.	900.00	81486.	.50	6.00	0.00	1.00	.01
5	2.	500.00	90534.	.50	6.00	0.00	1.00	.01
6	2.	500.00	218245.	.50	6.00	0.00	1.00	.01
7	2.	300.00	299807.	.50	6.00	0.00	1.00	.01
8	2.	300.00	253817.	.50	6.00	0.00	1.00	.01
9	2.	500.00	163532.	.50	6.00	0.00	1.00	.01
10	1.	1800.00	149449.	.50	6.00	0.00	1.00	.01
11	2.	800.00	20000.	.50	6.00	0.00	1.00	.01
12	2.	150.00	687106.	.50	6.00	0.00	1.00	.01
13	2.	1200.00	42217.	.50	6.00	0.00	1.00	.01
14	2.	900.00	42289.	.50	6.00	0.00	1.00	.01
15	2.	900.00	56072.	.50	6.00	0.00	1.00	.01
16	2.	900.00	74815.	.50	6.00	0.00	1.00	.01
17	2.	600.00	157828.	.50	6.00	0.00	1.00	.01
18	2.	600.00	194061.	.50	6.00	0.00	1.00	.01
19	2.	1500.00	109938.	.50	6.00	0.00	1.00	.01
20	1.	600.00	182671.	.50	6.00	0.00	1.00	.01

Sources:

QPA, MTBF: (DAU Technical Report, 1975:198-199)
UP: (Project Engineer, Rome Air Development Engineer
OTTR, RTS, NRTS: (Prime Item Development Specification, Digital Applique Unit, 1976)
CMMH, COND: (Microwave Radio Technician, Sacramento Air Logistics Center)

Table VII

FM Radio Cost Model Equipment Variables/Input Values

N	QPA	UP	MTBF	OTTR	CMMH	RTS	NRTS	COND
1	2.	800.00	10090.	2.70	5.00	1.00	0.00	0.00
2	2.	200.00	262080.	.20	6.00	0.00	1.00	.01
3	2.	250.00	262080.	5.00	5.00	0.00	1.00	.01
4	2.	175.00	262080.	5.00	6.00	0.00	1.00	.01
5	2.	175.00	262080.	5.00	6.00	0.00	1.00	.01
6	2.	200.00	262080.	5.00	6.00	0.00	1.00	.01
7	2.	200.00	262080.	5.00	6.00	0.00	1.00	.01
8	2.	3950.00	65520.	.50	6.00	1.00	0.00	0.00
9	2.	550.00	262080.	.80	6.00	1.00	0.00	0.00
10	2.	500.00	262080.	.20	6.00	1.00	0.00	0.00
11	2.	357.00	9038.	3.10	6.00	0.00	1.00	.01
12	2.	1123.00	20163.	4.50	6.00	0.00	1.00	0.00
13	2.	712.00	9705.	3.70	6.00	0.00	1.00	.01
14	1.	1763.00	37440.	3.70	5.00	0.00	1.00	0.00
15	1.	500.00	262080.	1.30	6.00	0.00	1.00	.01
16	2.	4475.00	15418.	2.10	5.00	0.00	1.00	0.00
17	2.	2096.00	8130.	2.70	5.00	0.00	1.00	0.00
18	2.	1835.00	10920.	1.80	6.00	0.00	1.00	0.00
19	1.	432.00	26208.	1.10	6.00	0.00	1.00	.01
20	1.	417.00	52415.	1.50	6.00	0.00	1.00	.01
21	1.	1957.00	65520.	5.10	6.00	0.00	1.00	0.00
22	2.	910.00	87360.	.40	6.00	0.00	1.00	.01
23	2.	1135.00	20160.	.80	6.00	0.00	1.00	0.00
24	2.	1145.00	43680.	1.50	6.00	0.00	1.00	0.00
25	1.	2200.00	23825.	4.30	0.00	1.00	0.00	0.00
26	2.	1800.00	65520.	4.30	0.00	1.00	0.00	0.00
27	2.	1755.00	52415.	3.70	0.00	1.00	0.00	0.00
28	2.	915.00	25000.	2.50	0.00	0.00	1.00	1.00
29	2.	458.00	87360.	6.30	0.00	0.00	1.00	.01
30	2.	250.00	14560.	2.70	0.00	0.00	1.00	.01

Sources:

QPA: (Technical Manual T.O. 31R5-4-135-2)
UP, CMMH, COND: (Microwave Radio Technician, Sacramento Air Logistic Center
MTBF, OTTR, RTS, NRTS: (Headquarters European Communications Area, Maintenance Analysis Office)

tion rate and time to repair were estimated by means of analogy of maintenance factor printouts of comparable systems. The typical repair time for set-up, fault isolation, repair and test of electronic modules and printed circuit boards could range from four to eight hours. A reasonable best estimate of six hours was used for this study. The percentage of condemned items for electronic modules was estimated as normally around one or two percent. A value of five percent is considered high for this type of equipment. The reader will note that in Tables VI and VII the best estimate of 6 hours for mean time to repair (CMMH) and .01 condemnation rate (COND) were used for both the DAU and the FM radio equipment. Results were also obtained by performing sensitivity analyses using the other values of these parameter estimates.

Digital Applique Unit and FM Radio Set Cost Estimates

The estimate of life cycle support costs for the digital applique unit and the FM analog radio sets were obtained through separate iterations of the cost model. This was done for the primary reason of determining the cost contribution each piece of equipment has toward the total of their combined support and operations cost.

The digital applique unit is a totally new piece of equipment yet to be produced, with a totally modular design concept using extremely high reliability parts. On the other hand, the FM radio equipment is presently installed and has been operating for the past few years. Although it also is a modular design concept, it is several years behind the DAU

both in modularity and current solid state parts usage. The FM radio set consists of several major chassis assemblies which are not of the remove and replace variety. Within these major assemblies are the pull out, plug in modules and printed circuit boards. Therefore, the maintainability of the two types of equipment vary because the FM radio equipment is less modular than the DAU.

Another key difference that is readily noticeable, is the significant difference in mean operating time between failures (MTBF). If the reader refers back to Tables VI and VII, he will note that the DAU MTBF is far greater than that of the FM radio. This should result in much lower maintenance support costs. This is one principal area where the uncertainty of input parameter values for MTBF must be tested with sensitivity analysis. The reader should be advised to remember that the values for MTBF were derived differently for the two types of equipment. The DAU values are results of engineering estimates. Experience has indicated that the theoretical values of MTBF obtained through engineering estimates are generally very optimistic. Test results or operational experience can be expected to produce lower MTBF values. For those reasons, the sensitivity analysis of the DAU will be accomplished by reducing MTBF values by increments of 25%. Actual operational maintenance data was used to determine the values of MTBF for the FM radio components. This data can include undetectable errors or bias which could result in MTBF values slightly different than actual. This

discussion points out some of the potential factors and areas of uncertainty that can result in wide cost variances between the two types of equipment.

Digital Applique Unit Costs

The total cost estimate of the DAU, using the input data base from Tables V and VI is $2,558,184. Individual cost element subtotals, CE1 through CE13 are presented in Table VIII. This table also lists each cost element's percentage of total cost. Initial investment costs amounted to 85% of the total cost estimate and recurring operations costs are only 15% of the total.

Investment Costs:

CE1+CE2+CE10+CE12+CE13=$2,180,868 (85%)

Operations Costs:

CE3+CE4+CE5+CE6+CE7+CE8+CE9+CE11=$377,316 (15%)

Table IX gives an additional breakdown of costs associated with initial spares, scheduled and unscheduled maintenance.

Sensitivity Analysis (DAU). Sensitivity analysis is a useful technique for accomplishing two objectives. First it can evaluate the effect of uncertainty in data. If there are key parameters about which the values are uncertain, the use of several values in a reasonable range will show how sensitive the results are to variations of the uncertain parameters. It also can be used to identify those parameters that have a significant influence on the final result.

Varying the Condemnation Fraction ($COND_i$). Cost model

Table VIII

Cost Model Results: Digital Applique Unit

Cost Element	1976 Dollars	% of Total
CE1 - Acquisition/Modification	1,545,708.	60.4
CE2 - Initial/Recoverable Spares	162,200.	6.3
CE3 - Non-Recoverable/Condemned Items	72,535.	2.8
CE4 - Unscheduled Repair/Organizational Level	9,150.	.4
CE5 - Unscheduled Repair/Intermediate Level	166,104.	6.5
CE6 - Scheduled Maint/Direct Labor	5,286.	.2
CE7 - Scheduled Maint/Indirect Factors	2,931.	.1
CE8 - Unscheduled Maint/Indirect Factors	99,138.	3.9
CE9 - Maintenance Reporting	11,912.	.5
CE10 - Technical Publications/Data	209,000.	8.2
CE11 - Inventory Management Cost	10,260.	.4
CE12 - Test Equipment Costs	155,480.	6.1
CE13 - Initial Training Costs	108,480.	4.2
TOTAL COST ESTIMATE (CE1 - CE13)	$2,558,184.	

Table IX

Additional Cost Breakdown of Selected DAU Cost Element Subtotals

Initial Spares	Dollars
·Site Level	103,600
·Base Supply	58,600
Initial Spares Total -	$162,200
Scheduled Maintenance	
·Direct Organizational Labor	5,286
·Travel Time (Personnel)	2,570
·Transportation (Vehicle)	361
Scheduled Maintenance Total -	$ 8,217
Unscheduled Maintenance	
·Direct Organizational Labor	9,150
·Direct Intermediate Labor	151,295
·Condemned Item Cost	12,191
·Parts Consumation Cost	60,344
·Travel Time (Personnel)	86,928
·Transportation (Vehicle)	12,210
·Transportation/Packaging (Module)	14,808
·Maintenance Reporting	11,912
Unscheduled Maintenance Total -	$358,838

input data values are not always available for newly developed hardware. A typical method of establishing a value for an unknown parameter value is by means of an analogy to a similar system. A best estimate of the value of $COND_i = .01$ was obtained by this method. As previously mentioned, the Reliability and Engineering Branch of the Sacramento Air Logistics Center considers the values of .01 and .02 as normal and a value of .05 is approaching the high side for electronic modules. Table X shows the results these three values of $COND_i$ have on the final cost estimate. Changing $COND_i$ from .01 to .05 increases the cost by $46,325 which is less than a 2% overall increase. Because there is no logical method to assign different values such as 0.0, .01, or .02 to each module, it was determined that the best estimate would be obtained by assigning a value of $COND_i = .01$ for all modules.

Varying Mean Time to Repair. The mean time to repair at both organizational and intermediate level maintenance were varied to visualize the effect on cost. The DAU specifications state that the mean corrective maintenance time (organizational level) should be no greater than 30 minutes and have a maximum corrective maintenance time no greater than 90 minutes (Prime Item Development Specifications for Modem, Digital Applique Unit, 1976:22). Table XI shows how the cost of organizational level maintenance varies when mean time to repair increases from .50 hours to 1.0, 1.5 and 2.0 hours. The effect is merely a linear increase and even the

Table X

Digital Applique Unit Cost with Respect to Varying Fraction of Condemned Parts ($COND_i$)

	$COND_i$ (Expressed as Fraction)		
	.01*	.02	.05
CE3: Non-Recoverable Condemned Items	$12,535.	$84,117.	$118,860
%Change from Best Estimate*	0	+ 16%	+ 64%
Total Life Cycle Support Cost Variation	$2,558,184.	$2,569,765	$2,604,509
% Change in Total Cost	0	+ .5%	+ 1.8%
Change in Total Cost	0	+ 11,581	+ 46,325

* (Best Estimate, $COND_i$ = .01, Source: Microwave Radio Technician, Sacramento Air Logistics Center)

200% change from .50 hours to 2.0 hours for repair time has little cost impact. The high reliability of the DAU components, tied with minimum remove and replace repair times at the organizational level, are the reasons these costs are so low.

The DAU specifications do not state a required module mean time to repair at the intermediate level of maintenance. This value would vary depending on the skill of the technician and complexity of the problem. The best estimate for this parameter, as stated earlier, was also provided by the Reliability and Engineering Branch at the Sacramento Air Lo-

Table XI

Digital Applique Unit Cost with Respect to Varying Organizational Level Maintenance Time to Repair ($OTTR_i$)

	Time to Repair (Hours)			
	.05*	1.0	1.5	2.0
CE4: Unscheduled Maintenance/ Organizational Level	$9,150.	$18,301.	$27,451.	$46,601
% Change from Specification Requirement*	0	100%	150%	200%
Total Life Cycle Support Cost Variation	$2,588,184.	$2,567,355.	$2,576,485.	$2,585,635
% Change in Total Cost	0	+ .35%	+ .7%	+ 1%
Change in Total Cost	0	+ $9,151	+ $18,301	+ $27,451

* (Development Specification Requirement Mean Time to Repair = .50 Hours).

gistics Center. The value of 6 hours was used in this study as the best estimate and Table XII indicates the cost results for CE5: Unscheduled Maintenance/Intermediate Level, with variations of mean time to repair of 4, 6, and 8 hours.

Varying Mean Time Between Failure ($MTBF_i$). Varying the parameter values of $COND_i$, organizational and intermediate mean time to repair in the previous sensitivity analyses indicated that the total cost did not change by more than 2%. The 10 year recurring costs totaled only $377,317 or 15% of the total cost estimate. Sensitivity analysis of the previously mentioned parameters had little effect on the total

Table XII

Digital Applique Unit Cost with Respect to Varying

Central Intermediate Maintenance Mean Time to Repair ($CMMH_i$)

	Time to Repair (Hours)		
	4	6*	8
CE5: Unscheduled Maintenance/ Intermediate Level	$115,672	$166,104	$216,535
Total Life Cycle Support Cost Variation	$2,507,752.	$2,555,184.	$2,608,616.
% Change in Total from Best Estimate*	1.8%	0	2%
Total Cost Change	$47,432	0	$53.432

* (Best Estimate, Time to Repair = 6 Hours, Source: Microwave Radio Technician, Sacramento Air Logistics Center

cost. These results are due to the high reliability of the digital applique unit components.

Referring back to Table VI, the $MTBF_i$ for the DAU modules range from a low of 20,000 hours to a high of 687,000 hours. Compare this to the $MTBF_i$ values from Table VII for the FM radio equipment that has a range from 4914 hours to 157,248 hours. Mean time between failure is the key parameter that can cause significant increases in follow-on operation costs. The cost elements CE2, CE3, CE4, CE5, CE8 and CE9 are all dependent on $MTBF_i$. Table XIII shows how reducing the engineering estimates on $MTBF_i$ by successive increments of 25% will effect the value of these cost elements and

Table XIII

Digital Applique Unit Cost with Respect to Varying Mean Time Between Failure (MTBF)

	MTBF (Expressed as Fraction of Engineering Estimate*)			
	1.00*	.75	.50	.25
CE1: Acquisition/Modification Cost	$1,545,708	$1,545,708	$1,545,708	$1,545,708
CE2: Initial Spares	162,200	195,000	229,600	332,400
CE3: Non-Recoverable/Condemned Item Cost	72,535	96,714	145,071	290,141
CE4: Unscheduled Maintenance/Organizational Level	9,150	12,200	18,301	36,601
CE5: Unscheduled Maintenance/Intermediate Level	166,104	221,471	332,207	664,414
CE6: Scheduled Maintenance/Direct Labor	5,286	5,286	5,286	5,286
CE7: Scheduled Maintenance/Indirect Costs	2,931	2,931	2,931	2,931
CE8: Unscheduled Maintenance/Indirect Costs	99,138	132,184	198,277	396,553
CE9: Maintenance Reporting	11,912	15,877	34,808	47,599
CE10: Technical Data Cost	209,000	209,000	209,000	209,000
CE11: Inventory Management Costs	10,260	10,260	10,260	10,260
CE12: Test Equipment	155,480	155,480	155,480	155,480
CE13: Training	108,480	108,480	108,480	108,480
Total Cost Estimate	$2,558,184	$2,710,591	$2,984,409	$3,804,853
% Change in Total Cost	0	+ 6%	+ 17%	+ 49%
Total Cost Change	0	+ $152,407	+ $426,225	+$1,246,669

* (Engineering Estimates of DAU Module MTBF, Source: Technical Report/DAU, 1975)

the impact on the total cost estimate. A 25% decrease in $MTBF_i$ increases the recurring operations costs from $377,316 to $529,723, which is a 40% increase in these costs. Similarly, a 50% decrease in $MTBF_i$ results in a cost estimate of $803,541 for operations cost or a 113% increase over the $377,316 recurring costs.

The values for $MTBF_i$ for the digital applique unit are based on theoretical engineering estimates of the prototype development contractor (Jessen, Technical Report; Digital Applique Unit, 1975:199). Engineering estimates are generally optimistic, that is, the predicted values of MTBF are higher than those obtained in actual field operational experience. For these reasons, the value of $MTBF_i$ may have the greatest degree of uncertainty associated with it than any of the other parameters. To compound the situation, it also is the only parameter that influences the cost associated with 6 of the 13 equations.

FM Radio Set Costs

The total cost estimate for the microwave FM analog radio sets using the input data base (1976 Dollars) from Tables IV and VI is $4,141,870. The individual cost element subtotals and their percentage of the total cost are presented in Table XIV. It should be noted that CE2: Initial Spares, CE12: Test Equipment, and CE13: Initial Training have values of 0.0 because these cost elements are sunk costs for this established operational system. Table XV gives an ad-

Table XIV

Cost Model Results: FM Radio Sets

Cost Element		1975 Dollars	% of Total
CE1	- Acquisition/Modification	102,000.	2.5
CE2	- Initial/Recoverable Spares	0.	0
CE3	- Non-Recoverable/ Condemned Items	946,293.	22.9
CE4	- Unscheduled Repair/ Organizational Level	732,351.	17.7
CE5	- Unscheduled Repair/ Intermediate Level	1,147,539.	27.7
CE6	- Scheduled Maint/ Direct Level	7,599.	0.1
CE7	- Scheduled Maint/ Indirect Factors	3,925.	0.1
CE8	- Unscheduled Maint/ Indirect Factors	1,039,966.	25.1
CE9	- Maintenance Reporting	124,807.	3.0
CE10	- Technical Publications/ Data	22,000.	0.5
CE11	- Inventory Management Cost	15,390.	0.4
CE12	- Test Equipment Costs	0.	0
CE13	- Initial Training Costs	0.	0
TOTAL COST ESTIMATE (CE1 - CE13)		$4,141,870.	

Table XV

Additional Cost Breakdown of

Selected FM Radio Cost Element Subtotals

Scheduled Maintenance	Dollars
* Direct Organizational Labor Cost	7,599
* Travel Time (Personnel) Cost	3,442
* Transportation (Vehicle) Cost	483
SCHEDULED MAINTENANCE TOTAL	$ 11,524
Unscheduled Maintenance	
* Direct Organizational Labor Cost	732,351
* Direct Intermediate Labor Cost	1,113,772
* Condemned Item Cost	561,588
* Parts Consumption Cost	384,705
* Travel Time (Personnel) Cost	911,884
* Transportation (Vehicle) Cost	128,081
* Transportation/Packaging (Module) Cost	33,767
* Maintenance Reporting Cost	124,807
UNSCHEDULED MAINTENANCE TOTAL	$ 3,990,955

ditional cost breakdown of scheduled and unscheduled maintenance. The costs associated with the FM radio equipment are predominantly recurring operations costs. Investment costs amount to only 3% of the total and recurring operation costs are 97%.

Investment Costs:

CE1+CE10=$124,000 (3%)

Operation Costs:

CE3+CE4+CE5+CE6+CE7+CE8+CE9+CE11=$4,017,870 (97%)

Sensitivity Analysis (FM Radio Sets). Most of the FM radio equipment data were obtained from actual maintenance data collected over the past 12 month period. Two particular parameters for which data were not available and best estimates had to be assumed, were the central intermediate level maintenance variables of $COND_i$ (fraction of failures condemned) and $CMMH_i$ (central maintenance manhours to repair the ith module). The same value of $COND_i = .01$ will be used for the FM components as was in the DAU analysis and for the same reasoning. To vary the value of $COND_i$ from .01 to .02 results in a proportional change of condemned item cost. Sensitivity analysis will be performed by varying $CMMH_i$ and $MTBF_i$ to illustrate their influence on the total cost estimate.

Varying Mean Time to Repair (Intermediate Level). As stated in the digital applique unit section, the value of mean time to repair at the intermediate maintenance

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level was a compromise between the range of 4 to 8 hours, estimated by the Sacramento Air Logistics Center, Reliability and Engineering Branch. Table XVI shows the resultant cost estimates when $CMMH_i$ values vary from 6 to 4 or 8 hours.

If the reader compares Table XVI with the comparable DAU Table XII, the costs for the FM radio unscheduled maintenance (CE5) is approximately seven times greater. Of course part of this increase cost can be expected because the FM radio set has 50% more modules/items than the DAU (30 vs 20). The increased number of parts accounts only for a small portion of the wide cost differential. The primary reason being the much higher failure rate of the FM radio equipment.

The researcher will take some liberty in the following example by comparing an average of means, but this is done merely to emphasize a point and not for precise accuracy. First consider that the average $MTBF_i$ of the twenty DAU modules is approximately 195,000 hours and that of the thirty FM radio work unit codes is only 41,000 hours. The ratio of these two figures ($\frac{195,000}{41,000} : \frac{4.8}{1}$) is approximately five. This implies that the FM radio set is generating five times the number of failures, five times the number of demands for intermediate level maintenance and therefore approximately five times the cost for this support. It was stated in the first section of Chapter III that reliability was a predominate equipment characteristic around which life cycle sup-

Table XVI

FM Radio Set Cost With Respect to Varying Intermediate Level Maintenance Time to Repair ($CMMH_i$)

	Time to Repair (Hours)		
	4	6*	8
CE5: Unscheduled Maintenance/ Intermediate Level	$776,282	$1,147,539	$1,518,796
Total Cost Estimate	3,776,613	4,141,870	4,513,127
% Change in Total From Best Estimate*	- 8.8%	-0-	+ 8.9%
Total Cost Change	- $365,257	-0-	+ $371,257

* (Best Estimate, Time To Repair = 6 Hours, Source: Microwave Radio Technician, Sacramento Air Logistics Center)

port cost models are developed. This comparison of the intermediate level maintenance costs for the DAU and the FM radios, demonstrates the influence reliability ($MTBF_i$) has on this cost element.

Varying Mean Time Between Failure ($MTBF_i$). A fundamental assumption of this study is that the maintenance data for the FM radio sets is the most appropriate and best available data to determine equipment parameter values. Therefore, the calculated values for $MTBF_i$ are considered to be reasonable representations of the FM radio equipments' reliability. The preceeding section demonstrated the effect $MTBF_i$ had on the cost element CE5, intermediate level maintenance. $MTBF_i$ is the key independent variable that has the greatest influ-

ence on recurring support costs. It affects the resultant cost of 6 of the model equations. This is best demonstrated, as in Table XVII, by varying $MTBF_i$ by ± 25%. A 25% improvement in $MTBF_i$ would result in a $798,187 decrease in total cost over the 10 year period. A 25% decrease in $MTBF_i$ would increase cost by $1,330,311. It is highly unlikely changes of this magnitude would occur and particularly not for all modules. In fact, the failure rate for most electronics equipment is considered to be fairly constant until it approaches what is termed a "wear-out period" near the end of its life cycle. During the wear-out period the failure rate increases rapidly. The FM radio equipment is approximately 3 to 5 years into its useful operating life of 10 to 12 years. Therefore, the failure rate is assumed to be constant and the best estimate is that which was obtained from the analysis of maintenance data.

Digital Applique Unit and FM Radio Combined Costs

The previous sections presented individual cost estimates for the digital applique unit and the FM radio sets. Due to the uncertainty of parameter values, sensitivity analysis was performed for each type of equipment to obtain the effect on cost. It also demonstrated the effect changes in parameter values can have on the incremental and final costs. These cost estimates and sensitivity analyses for each type of equipment were done separately in order to segregate the contribution each system would have toward the total cost of

Table XVII

FM Radio Set Cost with Respect to

Varying Mean Time Between Failure (MTBF)

	MTBF$_i$ (Calculated Value *± 25%)		
	MTBF$_i$*	-25%	+25%
CE1: Acquisition/ Modification Cost	$102,000	$102,000	$102,000
CE2: Initial Spares	0 (Sunk Cost)	0	0
CE3: Non-Recoverable/ Condemned Item Cost	946,293	1,261,725	757,035
CE4: Unscheduled Maintenance/Organizational Level	732,351	976,467	585,880
CE5: Unscheduled Maintenance/Intermediate Level	1,147,539	1,530,052	918,031
CE6: Scheduled Maintenance Direct Labor	7,599	7,599	7,599
CE7: Scheduled Maintenance Indirect Costs	3,925	3,925	3,925
CE8: Unscheduled Maintenance Indirect Costs	1,039,966	1,386,621	831,973
CE9: Maintenance Reporting	124,807	166,401	99,850
CE10: Technical Data Cost	22,000	22,000	22,000
CE11: Inventory Management Cost	15,390	15,390	15,390
CE12: Test Equipment	0 (Sunk Cost)	0	0
CE13: Training	0 (Sunk Cost)	0	0
Total Cost Estimate	$4,141,870	$5,472,181	$3,343,683
% Change in Total Cost	0	+ 32%	- 19%
Total Cost Change	0	+ $1,330,311	- $798,187

* (Calculated MTBF, Source: European Communications Area, Maintenance Analysis Office)

the combined system.

It was apparent that the major costs associated with the digital applique unit are predominantly investment costs. Due to the high reliability of the DAU, follow-on recurring costs were calculated at less than $400,000. The higher failure rate of the FM radio equipment resulted in an estimated recurring operations cost ten times that of the DAU, approximately $4 million over the ten year period.

The combined cost of the two systems, including both investment and operation costs, is estimated to be around $6,700,000 over their expected usage of ten years. Table XVIII summarized the previous cost estimates for both systems and lists the subtotals for each cost element of the model. Investment costs for the combined systems are $2,304,868 and are 34% of the total. Operation costs are $4,395,186 and 66% of the total.

Investment Costs:

CE1+CE2+CE10+CE12+CE13=$2,304,868 (34%)

Operation Costs:

CE3+CE4+CE5+CE6+CE7+CE8+CE9+CE11=$4,395,186 (66%)

The reader must be advised that these costs were all based on the best estimate of input values available at the time of the study. Most of the data were subject to varying degrees of uncertainty and sensitivity analysis demonstrated the potential effects of changes in parameter values. It is important to remember that the costs obtained are estimates subject to the validity and uncertainty of the input data base.

Table XVIII

Cost Model Results: Combined Digital Applique Unit and FM Radio Set Operations

Cost Elements	(1) DAU	(2) FM Radio	(1) + (2) DAU/FM	% of Total
CE1 -	$1,545,708	$102,000	$1,647,708	24.6
CE2 -	162,200	0	162,200	2.4
CE3 -	72,535	946,293	1,018,828	15.2
CE4 -	9,150	732,351	741,501	11.1
CE5 -	166,104	1,147,539	1,313,643	19.6
CE6 -	5,286	7,599	12,885	0.2
CE7 -	2,931	3,925	6,856	0.1
CE8 -	99,138	1,039,966	1,139,104	17.0
CE9 -	11,912	124,807	136,719	2.0
CE10 -	209,000	22,000	231,000	3.5
CE11 -	10,260	15,390	25,650	0.4
CE12 -	155,480	0	155,480	2.3
CE13 -	108,480	0	108,480	1.6
TOTAL	$2,558,184	4,141,870	$6,700,054	

Cost Tradeoff Comparison

The cost model has provided the methodology to estimate the relevant costs of the combined operations of the digital applique unit and the FM radio equipment. To utilize the model for cost tradeoff comparison among alternative digital equipments, requires input data from the competing digital radio. Because digital radio data is non-existent at this time, the following sections will demonstrate the use of the

model for a hypothetical, but potential future cost tradeoff between two competing systems.

New Digital Radio. In Chapter I it was stated that the Army is responsible for the development of a new digital radio. This radio, once fully developed, is projected to be the Defense Communication Agency's standard for most future digital requirements. Direction has been given to delay production of the digital applique unit until prototype development of the new digital radio nears completion. Possible consideration is being given to re-evaluate the use of either the DAU/FM radio combination or the digital radio in the Stage III portion of the program. Contracts for development of the new digital radio are expected to be let before the end of the fiscal year. Until progress is made in the digital radio development project, sufficient data will not be available to make a thorough analysis of the two options for Stage III digital equipment.

For example, the writer will assume various equipment characteristics for a hypothetical digital radio. The fundamental assumption is that a new digital radio would most likely emulate the characteristics of the digital applique unit. Using this analogy, the new digital radio is expected to be an all modular design with similar maintainability and reliability characteristics.

Input Data Base (Digital Radio). The following parameters are the only changes to be made from the initial data base listed in Table V.

N=50, the number of modules for the hypothetical digital radio was set equal to the sum of modules existing in the DAU/FM radio combination.

AQMOD=$65,000, program office personnel state that the Army production cost estimate is $62,500 and the researcher added $2,500 for installation cost.

The values of the system variables such as mean time to repair ($OTTR_i$, $CMMH_i$), module prices (UP_i), condemndation fraction ($COND_i$), and the not repairable this site fraction ($NRTS_i$) were maintained equal to those of the DAU/FM radio equipment. The reasoning is that the one variable which has the greatest influence on recurring support cost is the reliability measure of mean time between failures ($MTBF_i$). Therefore, the assumed failure rates for the fifty modules of the hypothetical digital radio were assigned values of $MTBF_i$ similar to the digital applique unit values. Table XIX lists the equipment input variable values used in the example.

For the new digital radio to be more cost effective than the DAU/FM radio combination, it will have to generate its savings impact in reducing the cost of recurring support. Because the FM radio is existing operational equipment, there are no costs associated with the acquisition of new FM radio units, initial spares, test equipment and initial training costs. The initial investment costs for the DAU/FM radio combination are primarily attributable to the digital applique unit. As such, investment costs for the new digital radio can be expected to exceed the DAU/FM radio initial costs because of the sunk costs related to the existing FM

Table XIX

Hypothetical Digital Radio Cost Model Equipment Variables/Input Values

N	QPA	UP	MTBF	OTTR	CMMH	RTS	NRTS	COND
1	1.	900.00	20000.	.50	6.00	0.00	1.00	.01
2	2.	150.00	687106.	.50	6.00	0.00	1.00	.01
3	2.	900.00	74736.	.50	6.00	0.00	1.00	.01
4	2.	900.00	81486.	.50	6.00	0.00	1.00	.01
5	2.	600.00	90534.	.50	6.00	0.00	1.00	.01
6	2.	600.00	218245.	.50	6.00	0.00	1.00	.01
7	2.	300.00	299807.	.50	6.00	0.00	1.00	.01
8	2.	300.00	253807.	.50	6.00	0.00	1.00	.01
9	2.	600.00	169592.	.50	6.00	0.00	1.00	.01
10	1.	1800.00	140449.	.50	6.00	0.00	1.00	.01
11	2.	800.00	20000.	.50	6.00	0.00	1.00	.01
12	2.	150.00	687106.	.50	6.00	0.00	1.00	.01
13	2.	1200.00	42217.	.50	6.00	0.00	1.00	.01
14	2.	900.00	42289.	.50	6.00	0.00	1.00	.01
15	2.	900.00	56072.	.50	6.00	0.00	1.00	.01
16	2.	900.00	74815.	.50	6.00	0.00	1.00	.01
17	2.	500.00	157828.	.50	6.00	0.00	1.00	.01
18	2.	600.00	194061.	.50	6.00	0.00	1.00	.01
19	2.	1500.00	109938.	.50	6.00	0.00	1.00	.01
20	1.	600.00	182671.	.50	6.00	0.00	1.00	.01
21	2.	800.00	20000.	2.70	6.00	1.00	0.00	0.00
22	2.	200.00	100000.	.20	6.00	0.00	1.00	.01
23	2.	250.00	100000.	5.00	6.00	0.00	1.00	.01
24	2.	175.00	100000.	5.00	6.00	0.00	1.00	.01
25	2.	175.00	100000.	5.00	6.00	0.00	1.00	.01
26	2.	200.00	100000.	5.00	6.00	0.00	1.00	.01
27	2.	200.00	100000.	5.00	6.00	0.00	1.00	.01
28	2.	3950.00	20000.	.60	6.00	1.00	0.00	0.00
29	2.	650.00	100000.	.80	6.00	1.00	0.00	0.00
30	2.	500.00	100000.	.20	6.00	1.00	0.00	0.00
31	2.	357.00	50000.	3.10	6.00	0.00	1.00	.01
32	2.	1023.00	50000.	4.50	6.00	0.00	1.00	0.00
33	2.	712.00	50000.	3.70	6.00	0.00	1.00	.01
34	1.	1763.00	50000.	3.70	6.00	0.00	1.00	0.00
35	1.	500.00	100000.	1.30	6.00	0.00	1.00	.01
36	2.	4476.00	50000.	2.10	6.00	0.00	1.00	0.00
37	2.	2096.00	50000.	2.70	6.00	0.00	1.00	0.00
38	2.	1895.00	50000.	1.80	6.00	0.00	1.00	0.00
39	1.	432.00	50000.	1.10	6.00	0.00	1.00	.01
40	1.	417.00	50000.	1.50	6.00	0.00	1.00	.01
41	1.	1867.00	50000.	5.10	6.00	0.00	1.00	0.00
42	2.	910.00	50000.	.40	6.00	0.00	1.00	.01
43	2.	1035.00	50000.	.80	6.00	0.00	1.00	0.00
44	2.	1145.00	50000.	1.50	6.00	0.00	1.00	0.00
45	1.	2200.00	100000.	4.90	0.00	1.00	0.00	0.00
46	2.	1800.00	100000.	4.30	0.00	1.00	0.00	0.00
47	2.	1756.00	100000.	3.70	0.00	1.00	0.00	0.00
48	2.	915.00	10000.	2.50	0.00	0.00	1.00	1.00
49	2.	458.00	100000.	6.70	0.00	0.00	1.00	.01
50	2.	250.00	50000.	2.70	0.00	0.00	1.00	.01

radio equipment.

Digital Radio Cost Estimate. The total cost estimate for the hypothetical digital radio is $4,936,864 in comparison to the $6,700,054 estimate previously obtained for the DAU/FM radio ten year support cost. Table XX lists the individual cost element subtotals for the two proposed systems. The reader will note that cost elements CE10 through CE13, reflect identical costs. For the purposes of this example, the costs related to technical publications (CE10), inventory management costs (CE11), test equipment costs (CE12) and training (CE13), were assumed to have no discernible difference between alternate systems. In this way, primary attention can be directed toward the recurring costs dependent on the reliability characteristics of the digital radio. Applying similar reasoning to the scheduled maintenance costs (CE6 and CE7) where the cost differential is minimal, no further discussion is needed.

Of the remaining cost element subtotals for the digital radio only two, CE1: Acquisition Costs and CE2: Initial Spares Costs, exceed the estimates for the DAU/FM radio equipment. That is because the new digital radio per unit acquisition and modification costs are $65,000 as compared to $48,000 each for the DAU/FM radio costs. Initial spares for the digital radio are computing costs of stocking 50 modules where the digital applique unit has to stock for only 20 modules. The FM radio values for these cost elements were sunk costs.

Table XX

Comparitive Cost Results

Hypothetical Digital Radio and DAU/FM Radio

Cost Element	Digital Radio	DAU/FM Radio
CE1 - Acquisition/Modification	$2,210,000.	$1,647,708
CE2 - Initial/Recoverable Spares	589,444.	162,200
CE3 - Non-Recoverable Condemned Items	714,565	1,018,828
CE4 - Unscheduled Repair Organizational Level	163,311.	741,501
CE5 - Unscheduled Repair/ Intermediate Level	354,856.	1,313,643
CE6 - Scheduled Maint/Direct Labor	7,599.	12,885
CE7 - Scheduled Maint/Indirect Factors	3,925.	6,856
CE8 - Unscheduled Maint/ Indirect Factors	332,621.	1,139,104
CE9 - Maintenance Reporting	39,933.	136,719
CE10 - Technical Publications/ Data	231,000.	231,000
CE11 - Inventory Management Cost	25,650.	25,650
CE12 - Test Equipment Costs	155,480.	155,480
CE13 - Initial Training Costs	108,480.	108,480
TOTAL COST ESTIMATE (CE1 - CE13)	$4,936,864	$6,700,054

The initial investment costs for the digital radio are $3,294,404 compared to $2,304,868 for the DAU/FM radio combination. Recurring operations costs are $1,642,460 and $4,395,186 for the digital radio and the DAU/FM radio equipment respectively.

Investment Costs:

CE1+CE2+CE10+CE12+CE13

Digital Radio (Initial Costs) = $3,294,404
DAU/FM Radio (Initial Costs) = $2,304,868

Recurring Costs:

CE3+CE4+CE5+CE6+CE7+CE8+CE9+CE11

Digital Radio (Recurring Costs) = $1,642,460
DAU/FM Radio (Recurring Costs) = $4,395,186

The differential cost between the totals of the two alternatives is $1,763,190 in favor of the hypothetical digital radio. This estimate does not take into account the time value of money. For a long-range capital investment decision of this type it is appropriate to compute the present value of future expenditures. The recurring operations costs are future expenses expected to occur over the ten year life cycle of the system. These future costs should be discounted to their present value and the comparison made on the total of the present value of initial investment and recurring costs.

For this example, the recurring operation costs for the two systems are assumed to be equally distributed over the ten year period. For an assumed 10% discount rate, the comparison of present values are now $4,304,352 and $5,007,464 for the digital radio and DAU/FM equipment respectively.

Using the present value method, the differential cost is now $703,112, still in favor of the digital radio. The present value analysis has the greatest effect on the DAU/FM radio values because of its larger future recurring costs. Table XXI shows present value calculations for discount rates of 6, 8, 10, and 12%. Comparing all present value estimates the hypothetical digital radio may be the most cost effective option.

This example was for demonstration purposes only and in no way reflects the actual situation. The intent was to point out how the developed support cost model can be used to compare alternatives. When sufficient data on the new digital radio becomes available, the model could be used to make a preliminary cost comparison. Analysis of cost model results could determine if higher initial investment costs could be amortized over the ten year period of reduced support costs.

Table XXI

Present Value Calculations for Varying Discount Rates

(Period = 10 years)

Discount Rate	Digital Radio	DAU/FM Radio
6%	$4,503,090	$5,539,280
8%	$4,396,330	$5,253,594
10%	$4,304,352	$5,007,464
12%	$4,222,558	$4,788,239

Summary

In this chapter, the researcher obtained the life cycle support cost estimates of the digital applique unit and the FM microwave radio equipment using the cost model developed in Chapter III. Initial discussion dealt with the input data base requirements of the model. Then the results of the cost model were presented along with the combined digital applique and FM radio equipment support cost estimate. This cost estimate spans a ten year period and amounts to a total of \$6,700,000. Due to uncertainty of various input data, the model was exercised using different selected parameter values and the results were examined for the effect on final cost. The chapter concludes with a demonstration of the model to provide life cycle support cost comparisons between equipment alternatives.

V. Summary

This chapter includes a summary, conclusions, and recommendation that resulted from the study.

Summary

The object of the Digital European Backbone Program is to improve the existing communications in Europe. The program will upgrade most of the existing operational equipment with modern, reliable, digital transmission subsystems. The program is being implemented in four stages. Stage I will utilize a Defense Communications System microwave radio modified to provide the needed digital capability for that segment. The newly developed digital applique unit (DAU), operating with an FM analog radio or the soon to be developed digital radio (Army DRAMA Project), are equipment alternatives for Stages II, III and IV. Preliminary directions have identified the digital radio to replace the older obsolete radios within Stage II. Digital radio requirements for Stage III are expected to be satisfied using the existing analog radios in combination with the digital applique unit recently developed by the Air Force. The digital applique unit was specifically developed to extend the operational use of the existing FM radios installed at the Stage III sites. The Stage IV equipment configuration has not yet been defined.

Because the DAU/FM analog radio equipment and the digital radio can perform the same function, either equipment alternative or combinations of equipments remain as candidates

for Stages II, III and IV. Final determinations of the digital equipment configuration for these stages are awaiting prototype development results of the digital radio. At that time, sufficient technical and cost data should be available to conduct an effective study comparing the alternatives.

This study focused on a proposed methodology for making the cost comparisons between equipment alternatives for Stage III of the Digital European Backbone Program. The methodology selected to accomplish this task was to develop a life cycle logistics support cost model representing the relevant initial investment costs, maintenance and supply support costs. The application of the model yields estimated cost results that indicate relative cost magnitudes and relative cost differential comparisons as figures of merit between equipment alternatives.

The developed model was exercised and cost estimates were obtained for the digital applique unit and the operational FM analog radio equipment. The cost estimate for the DAU/FM radio combination was $6,7000,000 for the ten year period. It was emphasized that this result was an estimate based on the best available data at the time of the study. The greatest difficulty encountered in using the model, was obtaining the extensive input data base requirements. Like all new developments, certain parameter values were not available for the digital applique unit. Although more detailed information was available for the FM radio sets, there were some deficiencies also. Best estimates of missing parameter values

were obtained by means of analogy to similar equipment.

Because of the uncertainty that normally exists in estimated values, sensitivity analyses were conducted. Selected parameter input values of both the digital applique unit and FM radio were varied to determine the effects they had on the total cost.

Next, the model was used to estimate the costs of the proposed digital radio using hypothetical parameter input values. The purpose was to illustrate the use of the developed model in a comparison of alternative equipment with different characteristics and costs. A brief analysis of the cost differences between initial investment and recurring costs was conducted using the present-value discounted cash flow method. This concluded the study and the demonstration of the utility of the developed cost model.

Conclusion

The decision criteria used in a cost tradeoff study must not only consider the costs to introduce the equipment into the Air Force inventory, but also it should include the expected costs over the equipments operational life. It is important therefore, that decision makers deliberating between alternative equipment choices are aware of both the one time investment costs and future recurring costs. The methodology developed in this study provides a useful tool for obtaining the significant initial investment costs and recurring maintenance and supply support costs. Although early esti-

mates of maintenance and supply support costs are not precise, they can provide a relative measure for discriminating between alternatives.

The support cost model developed in Chapter III computes recurring maintenance and supply costs as a function of the expected number of failures. Mean-time-between-failures (MTBF) is the parameter that is used to estimate the number of module failures. It was pointed out that the equipment reliability parameter, MTBF was the one variable having the greatest influence on recurring support costs. It is apparent that equipment with higher reliability (lower failure rates) will be less costly to support than equipment with lower reliability (higher failure rates), with all other things remaining equal.

This was not only demonstrated by sensitivity analysis, but also by a comparison of the digital applique unit and FM equipment results. Ninety percent of the total ten years recurring support costs are attributable to the less reliable FM radio equipment.

The conclusion the researcher draws from this, is that the not yet developed all digital radio could be a viable cost effective alternative for Stage III. If the new digital radio were to have the higher reliability characteristics assumed for the digital applique unit, it could conceivably be the least costly option.

Recommendation

When sufficient technical and cost data become available from the digital radio development, a tradeoff analysis between it and the DAU/FM radio equipment should be accomplished. It is recommended that the methodology used in this study be utilized to obtain the comparitive cost estimates for the two alternative systems.

However, cost should not be the sole criterion. Other factors that should possibly be considered are:

1. If possible, a projection of the useful life of the FM radios should be made. This study assumed a ten year operational period based on the digital applique unit's specification. The Stage III implementation schedule was 1978, which would place the FM equipment approximately five years into their operating life. Is it reasonable to assume they can be useful for the additional ten years or will their condition begin to deteriorate?

2. The selection of digital equipment for Stages II, III and IV should consider the interactions of using the same equipment for all three stages. The potential benefits derived from standardization of equipment, parts, training and documentation could have considerable impact toward reducing total program costs. Whereas the use of both alternatives in different stages has the effect of proliferation of equipment, parts, training and technical documentation.

3. Both systems must also be compared against each other in terms of equipment performance. One may provide greater versatility, better fault isolation features, built in test equipment or other desired features.

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Appendix A

Cost Model Equations and Data Element Definitions

Cost Model Equations

(Data Element Definitions follow the listing of Equations)

CE1 : Acquisition and/or Modification Cost

CE1 = (NO)(AQMOD)

CE2 : Initial Spares, Recoverable Items

$$CE2 = NSV \sum_{i=1}^{N} (SSTK_i)(UP_i) + NBS \sum_{i=1}^{N} (BSK_i)(UP_i)$$

where:

$$SDMEAN_i = \frac{(AMH)(QPA_i)}{(MTBF_i)} \; \frac{BSPT}{NSV}$$

$$BDMEAN_i = \frac{(AMH)(QPA_i)}{(MTBF_i)} \; \frac{CIPT}{NBS}$$

Determine $SSTK_i$ and $BSTK_i$ from:

$$\sum_{n=0}^{STK_i} \frac{(e^{-SDMEAN_i})(SDMEAN_i)^n}{n!} \geq CONF$$

$$\sum_{n=0}^{BSTK_i} \frac{(e^{-BDMEAN_i})(SDMEAN_i)^n}{n!} \geq CONF$$

CE3 : Non-Recoverable Item Costs

$$CE3 = 12\ PIUP \sum_{i=1}^{N} \frac{(AMH)(QPA_i)}{(MTBF_i)} [UP_i][(COND_i)(NRTS_i) + (PCF)(NRTS_i - COND_i)]$$

CE4 : Unscheduled Maintenance/Organizational Level

$$CE4 = 12\ PIUP \sum_{i=1}^{N} \frac{(AMH)(QPA_i)}{(MTBF_i)} [(OTTR_i)(OLR) + (OMMH)(OLR)(RTS_i)]$$

CE5 : Unscheduled Maintenance/Intermediate Level

$$CE5 = 12\ PIUP \sum_{i=1}^{N} \frac{(AMH)(QPA_i)}{(MTBF_i)} [(CMMH_i)(CLR)(NRTS_i) + (NRTS_i)(RTT_i)]$$

CE6 : Scheduled Maintenance/Direct Labor Costs

$$CE6 = 12 \sum_{j=1}^{L} \frac{PIUP}{SMI_j} [(SMH_j)(NO)(OLR)]$$

CE7 : Scheduled Maintenance/Indirect Costs (Unmanned Sites)

$$CE7 = 12 \sum_{j=1}^{L} \frac{PIUP}{SMI_j} [(MTT)(2)(OLR) + (NML)(CFM)][UMF]$$

CE8 : Unscheduled Maintenance/Indirect Costs (Unmanned Sites)

$$CE8 = 12\ PIUP \sum_{i=1}^{N} \frac{(AMH)(QPA_i)}{(MTBF_i)} [(MTT)(2)(OLR) + (NML)(CFM)][UMF]$$

CE9 : Maintenance Reporting

$$CE9 = 12\ (PIUP)(OLR) \sum_{i=1}^{N} \frac{(AMH)(QPA)}{(MTBF_i)} [ART] + \sum_{j=1}^{L} \frac{(.1)(ART)}{(SMI_j)}$$

CE10: Technical Data Costs

CE10= TD(TO + TI)

CE11: Inventory Management Costs

CE11= NNM[IMC + (PIUP)(RMC)]

CE12: Test Equipment and Support Equipment Costs

CE12= NSV(COTE) + CISE

CE13: Training Costs

CE13= THR[CCTH + NPT(TCH)] + OTHR[G(CMIH) + ONPT(OLR)]

Cost Model Data Element Definitions

Parameters/Data Elements

AHR - Average monthly operating hours per piece of equipment (24×30 = 720 hours per month).

AMH - Average monthly operation hours per piece of equipment multiplied by the number of units to give system total operating hours per month (AMH = AHR×NO).

AQMOD - The unit acquisition cost for quantity procured and/or the modification cost per piece of equipment modified (Digital European Program Office).

ART - Average maintenance report time (ART = .65 Hour; Source: Logistic Support Cost User's Guide, 1975: 2-2).

$BDMEAN_i$ - Mean demand for the ith component at base supply level.

BSPT - Base supply pipeline time. The average base supply cycle time in response to a site initiated parts request (BSPT = .50 month; Source: European Communications Area.

$BSTK_i$ - Base stock level of the ith component.

CCTH - Contract cost per training hour for Type I training (CCTH = $245/hour; Source: Air Training Command Cost and Planning Factors Office).

CE1 - Total acquisition and/or modification cost.

CE2 - Acquisition cost of initial spares at site and base supply points.

CE3 - Non-recoverable item cost, includes parts replaced and discarded during corrective maintenance, and replenishment cost of condemned items.

CE4 - Direct organizational labor costs to perform unscheduled maintenance.

CE5 - Direct intermediate maintenance labor costs to perform unscheduled corrective maintenance.

CE6 - Direct organizational labor costs to perform scheduled preventive maintenance routines.

CE7 - Indirect scheduled maintenance costs associated with travel to and from unmanned communication sites.

CE8 - Indirect unscheduled maintenance costs associated with travel to and from unmanned communication sites.

CE9 - Cost associated with direct labor expended to complete maintenance reporting paperwork.

CE10 - Initial technical data costs of published technical instructions and technical orders.

CE11 - Inventory management costs. The cost associated with initial and recurring supply management costs of modules and components.

CE12 - Test equipment and support equipment costs.

CE13 - Initial training costs.

CFM - Vehicle cost factor per mile (CFM = $.16 per mile; Source: Defense Communications Agency Circular 600-60-1, 1972:24-39).

CISE - Cost of central intermediate maintenance special support equipment (CISE = $118,170; Source: Digital Applique Unit prototype development contractor).

CIPT - Central intermediate maintenance repair pipeline time (CIPT = 1.0 month; Source: European Communications Area).

CLR - Central intermediate maintenance labor rate (CLR = $18.05; Source: Logistics Support Cost User's Guide, 1975:2-4).

CMIH - Average cost per hour of mobile instructor, to include labor rate, retirement, perdiem, and supplies (CMIH = $15.00/hour; Source: Air Training Command Cost and Planning Factors unofficial estimate for this thesis).

$CMMH_i$ - Central intermediate maintenance manhours expected per repair of the ith module/item ($CMMH_i$ = 6 hours; Source: Sacramento Air Logistics Center).

$COND_i$ - Condemnation of the ith component, expressed as a fraction of failures ($COND_i$ = .01; Source: Sacramento Air Logistics Center).

CONF - Confidence level factor for desired stock level availability.

COTE - Test equipment cost per site or mobile maintenance van (COTE = \$2665 per installation; Source: Contractor estimate).

CPP - Transportation, packaging, and handling cost per pound (CPP = \$.53 per pound; Source: Air Force Logistics Command Manual 66-18, 1970:15-3).

i - The subscript identifying each component/module.

IMC - Initial management cost to introduce a new item of supply into the Air Force inventory (IMC = \$46.60 per item; Source: Logistics Support Cost User's Guide, 1975:2-1).

j - The subscript identifying each scheduled maintenance routine.

L - Number of different scheduled maintenance routines (Source: European Communications Area).

$MTBF_i$ - Expected mean-time-between-failures of the ith component, expressed in operating hours.

MTT - Mean travel time to complete round trip between unmanned sites and mobile maintenance facilities.

N - The number of different components or modules per piece of equipment.

NBS - The number of host base supply points.

NML - Average number of miles traveled to complete round trip between mobile maintenance facility and unmanned sites.

NPT - Number of personnel to receive Type I, contractor training.

NO - Total number of units procured and/or the number of modifications required.

$NRTS_i$ - Fraction of failures of ith module/item which is transferred to intermediate maintenance for repair (Not repairable this station).

NSV - The number of sites and mobile maintenance vans maintaining stock level of spares and test equipment.

OLR - Organizational labor rate of maintenance technician. (OLR = \$13.10; Source: Logistics Support Cost User's Guide, 1975:2-4).

OMMH - The average number of organization shop maintenance manhours expended for site repair of the ith module/item.

ONPT - The number of organizational maintenance personnel to be trained.

OTHR - The number of organizational training hours required.

$OTTR_i$ - Organizational time to repair is the average time in man-hours per failure of the ith module/component to test, remove, replace, and realign, to put equipment into operable condition.

PCF - Parts consumption cost factor expressed as a fraction of the recoverable parts cost (PCF = .05; Source: Defense Communications Agency Circular 600-60-1, 1972:22-4).

PIUP - Projected inventory usage period expressed in years (PIUP - 10 years).

QPA_i - Quantity per application of the ith component. The maximum number of like components installed in a single unit or radio set.

RMC - Recurring management cost to maintain an item in the active Air Force Inventory (RMC = \$104.20 per item per year; Source: Logistic Support Cost User's Guide, 1975:2-1).

RTS_i - Fraction of removals of the ith item or module which are repaired at the organizational shop level and returned to service (Repair this station).

RTT_i - The average round trip transportation cost to ship the ith module to CIMF for repair and return to host base supply ($RTT_i = 2 \cdot WT_i \cdot CPP$).

$SDMEAN_i$ - Mean demand for the ith module or component at communications site level.

SMH_j - The average man-hours required to perform the jth scheduled maintenance routine.

SMI_j - The established interval between the jth scheduled maintenance routine, expressed in months or fraction of a month.

$SSTK_i$ - The site stock level of the ith component.

TCH - Trainees cost per hour (TCH = $15.00/Hour; Source: Air Training Command, Cost and Planning Factors Office).

TD - Average cost per original page of technical documentation (TD = $220.00 per page; Source: Logistics Support Cost User's Guide, 1975:2-2).

THR - Number of Type I contractor training hours required.

TI - Estimated number of pages of technical instruction or intermediate technical documentation.

TO - Estimated number of pages of organizational level technical documentation and technical orders required to maintain the equipment.

UMF - Fraction of unmanned sites to total number of sites.

UP_i - The unit price of the ith module/component.

WT_i - Average weight per module/item.

Vita

Major Galen J. Rose, USAF, was born in Mitchell, South Dakota in 1940. He received a Bachelor of Science in General Studies from Montana State University in 1962. He received a second Bachelor of Science in Electrical Engineering from Colorado State University in 1969. Commissioned through ROTC in 1962, he served from 1962 to 1967 as a ground electronics officer. From 1967 to 1969 he attended Colorado State University under an AFIT program. From 1969 to 1974 he served as Configuration Management Officer and Operations Officer at the New Hampshire Satellite Tracking Station of the Satellite Control Facility. His last assignment was as a System Test Officer with the 6594th Space Test Group, Vandenberg AFB, California. His next assignment will be to Electronic Systems Division as a Program Control Officer.

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REPORT DOCUMENTATION PAGE

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This study provides a cost-based methodology for comparing alternative fixed ground communications radios. The study develops and demonstrates a life cycle logistics support cost model representing relevant initial investment costs and recurring maintenance and supply support costs. The scope of the study addresses only Stage III of the Digital European Backbone Upgrade Project. The cost model developed is an accounting model CONT

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that aggregates the cost of thirteen separate cost element equations and requires 54 input data values. This methodology provides a systematic approach to estimating the relevant costs of proposed equipment options over their expected usage period. The model yields estimated cost results that indicate relative cost magnitudes and relative cost differential comparisons as figures of merit between equipment alternatives.

END ABSTRACT

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